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where the yield was only slightly below normal for the 0.5 per cent of lime, while in the 0.5 per cent addition, the fourth corn yield was greater than the check crops.

That there is a gradual re-establishment in the soil is shown by the crops representing the recovery crops in the soil after each period as has been shown above.

ALKALI STUDIES: IV. TOLERANCE OF OATS FOR ALKALI IN IDAHO SOIL[1]

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Tolerance studies of certain definite crops for Idaho soil have been presented in three previous papers (2, 3, 4). The present paper deals with the tolerance of oats toward alkali salts. Four crops of oats were grown. All experimental conditions were kept similar to the barley series described in "Alkali Studies: III." The same plan of presenting data has been used in the present paper as was used in the former articles.

DESCRIPTION OF CROPS

Crop 1

Twelve seeds of Idamine oats were planted on August 8, 1922. The crop was grown throughout the fall and winter months when sunlight was scarce. The weather conditions were somewhat reflected in the type of growth of the oats: There was luxuriant leaf growth but very little grain production; the heads formed but did not fill; the stalks were heavy and the crop grew very tall. Photographs were taken on March 1. On March 6, 1923, the crop was harvested and the total dry weight of each crop was recorded.

Crop 2

Crop 2 was planted on March 19, 1923, using Idamine oats. The soil had been thoroughly stirred to a depth of 4 or 5 inches and brought up to the optimum moisture content. During the growth of crop 2 it was especially noticed that the carbonate treated pots produced extremely thick, wide leaves of a blue color. The high concentrations of carbonate killed the plants at a height of three or four inches. Photographs were taken on April 23, 1923, to show this early condition of oats grown on the carbonate soil. Throughout the growth, even in this second crop, the oats grown on the check soils looked yellow and somewhat starved.

Crop 2 began to head out during the latter part of May and continued to show good growth during June and July. The heads filled very satisfactorily. The plants were harvested on August 2, 1923.

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Crop 3

After harvesting crop 2 the soils were thoroughly cultivated and again sampled, moistened and replanted with Idamine oats on August 17, 1923. Germination was very rapid. In a short time many of the oats on the carbonate treatments died. The oats on the chloride treatments grew very slowly, but maintained life and matured early, often with well-filled heads. Because of the short, cloudy days the growth was naturally slow. The rate of heading out seemed to be influenced more by weather conditions than by salt treatments. This crop produced poor grain, due in general to poor weather conditions. This series was photographed February 9 and harvested February 12, 1924.

Crop 4

After the third crop of oats was removed, the soil was sampled and again cultivated. On March 4, 1924 the fourth crop was planted. Germination was very rapid because of the favorable weather. The plants grown on the heavy carbonate treatments died after reaching a height of 3 to 4 inches. The greater part of the crop grew in a rapid and satisfactory manner and started to head out on May 15, 1924. The growth of the oats approached normal field conditions: it was not excessive or rank; and the plants, which stooled very little, had a tendency to produce grain rather than straw. The straw was not coarse but so sturdy that the crop stood up better than any of the preceding ones. This crop was harvesed June 13, 1924.

YIELD OF CROPS ON CHECK SOIL

The yield in grams of dry matter of the crops on the check soil is as follows: First crop, 61.8; second crop, 15.5; third crop, 16.8; fourth crop, 19.4. For the sake of brevity, only the percentage yield, considering the check as 100 per cent, is given in the table.

SINGLE-SALT TREATMENTS

In the single sodium carbonate treatments, the salts are toxic to oats in all combinations, the toxicity increasing as the salt content increases. In crop two, there is stimulation in the 0.2 and 0.4 per cent additions, the 0.4 per cent showing a greater stimulation than the 0.2 per cent. Above the 0.4 per cent concentration no growth takes place. Crop 3 shows a slight stimulation in growth for the 0.2 per cent treatment, with the 0.4 per cent treatment showing only a 50 per cent yield, following the heavy yield of this treatment in the second crop. The higher concentrations of sodium carbonate, 0.6 and 0.9 per cent, produced failures for the third crop. In the fourth crop all yields are below normal, the only outstanding fact being that the 0.6 per cent addition produced a 56.5 per cent yield, which shows, when the yield of crop is considered, that the soil is gradually recovering from this high concentration of sodium carbonate. In all cases the highest concentration of sodium carbonate resulted in crop failure.

TABLE 1

Soil treatments, salt recovery, and crop yield
Single-salt combinations

NUMBER	TREATMENT Na_2CO_3 per cent	$NaCl$ per cent	Na_2SO_4 per cent	FIRST CROP yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	$NaCl$ per cent	Na_2SO_4 per cent	SECOND CROP yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	$NaCl$ per cent	Na_2SO_4 per cent	THIRD CROP yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	$NaCl$ per cent	Na_2SO_4 per cent	FOURTH CROP yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	$NaCl$ per cent	Na_2SO_4 per cent
135	Check			100.0	0.000	0.033	0.000	0.016	100.0	0.000	0.025	0.002	0.016	100.0	0.000	0.028	0.000	0.015	100.0	0.000	0.024	0.000	0.018
81	0.2			66.0	0.048	0.098	0.000	0.011	138.8	0.022	0.086	0.000	0.017	109.2	0.044	0.086	0.000	0.006	93.2	0.023	0.091	0.000	0.006
83	0.4			36.4	0.102	0.154	0.000	0.015	224.3	0.076	0.153	0.000	0.015	49.7	0.111	0.150	0.000	0.010	82.8	0.054	0.138	0.000	0.009
85	0.6			21.8	0.176	0.238	0.009	0.014	0.3	0.132	0.189	0.000	0.015	5.3	0.110	0.185	0.000	0.011	56.5	0.103	0.179	0.000	0.011
87	0.9			0.0	0.258	0.302	0.007	0.014	0.0	0.192	0.263	0.006	0.018	0.0	0.195	0.266	0.026	0.007	0.0	0.158	0.238	0.021	0.011
89		0.2		84.2	0.005	0.024	0.179	0.013	106.8	0.002	0.024	0.141	0.016	129.8	0.002	0.032	0.169	0.004	90.5	0.005	0.044	0.071	0.008
91		0.4		57.6	0.000	0.030	0.203	0.005	114.7	0.000	0.026	0.181	0.014	84.5	0.005	0.024	0.111	0.005	90.6	0.005	0.044	0.101	0.005
93		0.8		0.0	0.000	0.031	0.314	0.009	97.1	0.000	0.025	0.273	0.013	89.5	0.016	0.031	0.217	0.008	127.5	0.000	0.037	0.210	0.011
95			0.2	84.4	0.000	0.027	0.005	0.209	154.2	0.000	0.021	0.012	0.195	118.8	0.000	0.019	0.015	0.161	118.4	0.000	0.027	0.024	0.187
97			0.4	92.7	0.000	0.020	0.003	0.393	122.5	0.000	0.015	0.000	0.351	108.8	0.000	0.021	0.000	0.304	118.6	0.000	0.023	0.000	0.329
99			0.8	73.4	0.000	0.019	0.000	0.712	115.3	0.000	0.016	0.000	0.625	111.9	0.000	0.021	0.000	0.612	119.0	0.000	0.019	0.000	0.535
101			1.2	39.9	0.000	0.021	0.013	0.935	177.4	0.000	0.016	0.015	0.678	149.2	0.000	0.019	0.019	0.749	116.3	0.000	0.023	0.014	0.636
103			1.5	37.5	0.000	0.024	0.004	1.085	90.5	0.000	0.020	0.008	0.935	102.1	0.000	0.024	0.006	0.922	105.4	0.000	0.018	0.000	0.956
105			2.4	43.3	0.000	0.019	0.060	1.468	90.1	0.000	0.016	0.095	1.377	14.6	0.000	0.019	0.079	1.160	52.4	0.000	0.016	0.082	1.205

TABLE 2

Soil treatments, salt recovery and crop yield

Two-salt treatments in which sodium carbonate is the basic treatment

NUMBER	TREATMENT			FIRST CROP					SECOND CROP					THIRD CROP					FOURTH CROP				
	Na₂CO₃	NaCl	Na₂SO₄	Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄	Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄	Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄	Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
81	0.2			66.0	0.048	0.098	0.000	0.011	138.8	0.022	0.086	0.000	0.017	109.2	0.044	0.086	0.000	0.006	93.2	0.023	0.091	0.000	0.006
111	0.2	0.3		93.7	0.028	0.074	0.180	0.007	76.2	0.031	0.077	0.123	0.017	140.9	0.046	0.084	0.088	0.011	120.3	0.040	0.076	0.086	0.011
113	0.2	0.6		32.8	0.020	0.067	0.342	0.006	45.3	0.020	0.056	0.197	0.016	50.3	0.038	0.071	0.235	0.009	160.8	0.039	0.074	0.165	0.007
127	0.2		0.4	88.7	0.019	0.072	0.003	0.401	152.8	0.027	0.060	0.000	0.329	101.4	0.032	0.069	0.000	0.277	185.2	0.021	0.064	0.002	0.244
129	0.2		0.6	69.4	0.015	0.074	0.000	0.530	141.2	0.030	0.063	0.000	0.372	117.0	0.038	0.071	0.000	0.375	131.2	0.023	0.066	0.000	0.358
131	0.2		1.0	50.0	0.015	0.080	0.000	0.732	54.1	0.023	0.055	0.000	0.616	53.2	0.030	0.066	0.000	0.716	103.2	0.018	0.060	0.000	0.643
83	0.4			36.4	0.102	0.154	0.000	0.015	224.3	0.076	0.153	0.000	0.015	49.7	0.111	0.150	0.000	0.010	82.8	0.054	0.138	0.000	0.009
107	0.4	0.1		59.3	0.084	0.138	0.071	0.027	154.2	0.071	0.142	0.054	0.041	152.2	0.084	0.133	0.050	0.025	187.1	0.087	0.134	0.034	0.022
133	0.4		0.2	34.5	0.074	0.157	0.000	0.108	156.3	0.080	0.147	0.000	0.093	187.7	0.092	0.147	0.000	0.113	105.0	0.076	0.136	0.000	0.057
85	0.6			21.8	0.176	0.238	0.009	0.014	30.0	0.132	0.189	0.000	0.015	5.3	0.110	0.185	0.000	0.011	50.5	0.103	0.179	0.000	0.011
109	0.6	0.1		4.5	0.133	0.213	0.066	0.014	30.7	0.105	0.170	0.073	0.018	70.4	0.136	0.181	0.068	0.012	36.6	0.122	0.183	0.045	0.011
137	0.6		0.2	4.7	0.141	0.212	0.000	0.107	0.3	0.124	0.185	0.012	0.088	7.7	0.126	0.192	0.009	0.087	8.5	0.122	0.179	0.000	0.080
115	0.6	0.6		10.8	0.089	0.162	0.395	0.016	6.4	0.103	0.145	0.413	0.018	13.4	0.104	0.153	0.387	0.011	42.8	0.092	0.147	0.381	0.010
141	0.6		0.8	10.6	0.139	0.199	0.013	0.395	2.9	0.103	0.163	0.006	0.569	7.4	0.122	0.185	0.004	0.466	25.3	0.085	0.170	0.000	0.456

The 0.2 and 0.4 per cent sodium chloride additions are less toxic to plant growth in the first crop than similar sodium carbonate treatments and are less stimulating than these carbonate treatments in the second crop. In the third crop the 0.2 per cent additions continue to be stimulating and the 0.4 per cent addition results in an almost normal crop. Crop 4 shows yields slightly below normal in the 0.2 and 0.4 per cent treatments. The 0.8 per cent sodium chloride addition produces no growth in crop 1, nearly normal growth in crops 2 and 3, and a stimulated growth in crop 4. This is a good example illustrating the power of a soil to recover from excessive salt concentrations.

Sodium sulfate treatments are toxic to crop 1, the toxicity increasing slightly with increase in concentration. In crop 2 there is stimulation with all treatments up to 1.5 per cent. Higher concentrations produce yields slightly below normal. Crops 3 and 4 show maintained stimulation in all treatments except the highest concentration. The addition of 1.2 per cent sodium sulfate shows the highest stimulation throughout the second, third and fourth crops. All the sulfate treatments maintain a much higher level of production than the carbonate or chloride treatments.

TWO-SALT TREATMENTS

In table 2 data are presented for two-salt combinations in which sodium carbonate is used as the basis of comparison. These data indicate that combinations of salts often show results differing from those shown by each salt in the individual treatments.

In the first crop 0.2 per cent sodium carbonate alone produces a heavy cut in yield resulting in 66 per cent of a normal growth. When 0.3 per cent sodium chloride is added to this treatment, the amount of growth increases to 93.7 per cent of normal. There is no stimulation in crop 2; but there is stimulation in crops 3 and 4. In the heavier additions of sodium chloride, the decrease in crop 1 is almost the algebraic sum of the respective individual influences of the amount of salts used. High toxicity is shown in crops 2 and 3. Crop 4 shows that the soil has recovered from the toxic load to the extent that there is a stimulation of 60 per cent above the normal crop.

The addition of 0.4 per cent sodium sulfate to the basic 0.2 per cent sodium carbonate treatment produces a high yield in crop 1, increased stimulation in crop 2, normal growth in crop 3, and extreme stimulation in crop 4. The 0.6 per cent sulfate treatment approaches the expected toxicity in crop 1, slightly stimulates crop 2, and maintains stimulation in crops 3 and 4. The 1 per cent addition produces practically a 50 per cent yield in the first three crops and slightly surpasses a normal yield in crop 4.

As we have observed before, 0.4 per cent added sodium carbonate gives a low yield in crop 1, with excessive stimulation in crop 2, followed by rather heavy toxicity in crop 3, which is not overcome even in crop 4. With very small amounts of sodium chloride or sulfate, there is the high toxicity in crop 1, a 50 per cent stimulation in crop 2, and even greater stimulation

TABLE 3

Soil treatments, salt recovery and crop yield

Two-salt combinations in which sodium sulfate is the basic treatment

NUMBER	TREATMENT			FIRST CROP					SECOND CROP					THIRD CROP					FOURTH CROP				
	Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
95			0.2	84.4	0.000	0.027	0.005	0.209	154.2	0.000	0.021	0.012	0.195	118.8	0.000	0.019	0.015	0.161	118.4	0.000	0.027	0.024	0.187
133	0.4		0.2	34.5	0.074	0.157	0.000	0.108	156.3	0.080	0.147	0.000	0.093	187.7	0.092	0.147	0.000	0.113	105.0	0.076	0.136	0.000	0.057
137	0.6		0.2	4.7	0.141	0.212	0.000	0.107	0.3	0.124	0.188	0.012	0.088	7.7	0.126	0.192	0.009	0.087	8.5	0.122	0.179	0.000	0.080
139	0.8		0.2	0.0	0.240	0.309	0.028	0.132	0.0	0.200	0.276	0.014	0.139	0.0	0.197	0.272	0.011	0.018	0.0	0.160	0.237	0.000	0.116
121		0.3	0.2	66.1	0.002	0.023	0.194	0.204	138.0	0.000	0.019	0.175	0.182	9.3	0.005	0.024	0.140	0.135	88.3	0.000	0.038	0.128	0.131
123		0.6	0.2	5.9	0.002	0.027	0.380	0.178	53.6	0.000	0.021	0.340	0.159	35.1	0.002	0.022	0.247	0.134	98.1	0.000	0.033	0.239	0.128
97			0.4	92.7	0.000	0.020	0.003	0.393	122.5	0.000	0.015	0.000	0.351	108.8	0.000	0.021	0.000	0.304	118.6	0.000	0.023	0.000	0.329
117		0.1	0.4	71.8	0.002	0.035	0.092	0.363	120.8	0.000	0.018	0.083	0.433	96.6	0.000	0.028	0.085	0.354	121.5	0.000	0.025	0.067	0.350
127		0.1	0.4	88.7	0.019	0.072	0.003	0.401	152.8	0.027	0.060	0.000	0.329	101.4	0.032	0.069	0.000	0.277	85.2	0.021	0.064	0.002	0.244
99	0.2		0.8	73.4	0.000	0.019	0.000	0.712	115.3	0.000	0.016	0.000	0.625	111.9	0.000	0.021	0.000	0.612	119.0	0.000	0.019	0.000	0.535
141	0.6		0.8	10.6	0.139	0.199	0.013	0.395	2.9	0.103	0.163	0.006	0.569	7.4	0.122	0.185	0.004	0.466	25.3	0.085	0.170	0.000	0.456
125		0.6	0.6	9.2	0.000	0.024	0.321	0.450	22.7	0.000	0.015	0.357	0.475	20.0	0.000	0.019	0.318	0.382	81.7	0.000	0.028	0.268	0.429
119		0.1	0.8	58.0	0.000	0.023	0.057	0.645	90.8	0.000	0.017	0.061	0.541	72.0	0.000	0.020	0.055	0.519	128.5	0.000	0.024	0.053	0.481

in crop 3. In crop 4 the chloride and carbonate combination produces a stimulation of 87 per cent above normal, although the sulfate and carbonate treatment yields only 5 per cent above normal.

The addition of 0.6 per cent sodium carbonate which is very toxic when alone, continues to be so in all treatments, whether in combination with high or low chlorides or sulfates, and continues toxic throughout all four crops grown. Only in the addition of 0.6 per cent sodium carbonate with 0.1 per cent sodium chloride is there any evidence that shows any power to overcome the toxic load; this combination produces a 30, 70 and 36 per cent yield in crops 2, 3 and 4 respectively.

A noteworthy fact in this series is the high stimulation in crop 4 for all two-salt combinations of 0.2 and 0.4 per cent sodium carbonate. Chlorides and sulfates are about equally effective in this respect, both being more stimulating at relatively low concentrations.

When sodium sulfate additions are chosen as the basis for comparison in table 3, certain data are found to be repetitions of table 2. They are repeated in order to compare the influence of other regularly variable factors than those referred to in table 2. In combinations of 0.2 per cent sodium sulfate, the sodium carbonate or chloride added becomes the predominating influence, producing yields similar to the individual sodium carbonate and sodium chloride treatments.

Combinations of 0.4 per cent sodium sulfate with additions of low carbonates and chlorides show results varying only slightly from the individual 0.4 per cent concentrations of sodium sulfate as indicated by crop yields; namely, a decrease in crop 1, stimulation by carbonates in crop 2, and a normal yield in crop 3. In crop 4 the chloride additions show high stimulation and the carbonates high toxicity. Because of the total concentration of salts 0.8 per cent of sodium sulfate in combinations shows high toxicity.

In table 4 an attempt is made to group the treatments in relation to certain changes in sodium chloride content. Since there are no single additions of 0.1 or 0.3 per cent sodium chloride, the 0.2 and 0.4 per cent additions are presented for comparison. With additions of 0.3 per cent sodium chloride, the first crop shows decreased toxicity in additions of 0.2 per cent sodium carbonate or 0.2 per cent sodium sulfate. In crop 2 the carbonate addition shows toxicity, but the sulfate shows stimulation. This is reversed in crop 3, with almost complete failure in the sulfate combination. In crop 4 both combinations show a tendency to approach normal yields.

High concentrations of sodium chloride are very toxic in the first crop, approach normality in crops 2 and 3, and show stimulation in crop 4. In all combinations with other salts the toxicity is increased above the chloride alone except the fourth crop in the 0.2 per cent sodium carbonate with 0.6 per cent sodium chloride treatment, where the stimulation reaches 60 per cent above normal. The other treatments tend toward normality in the fourth crop.

TABLE 4

Soil treatments, salt recovery and crop yield

Two-salt combinations in which sodium chloride is the basic treatment

NUMBER	TREATMENT			FIRST CROP					SECOND CROP					THIRD CROP					FOURTH CROP				
	Na_2CO_3	NaCl	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	NaCl	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	NaCl	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	NaCl	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	NaCl	Na_2SO_4
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
89		0.2		84.2	0.005	0.024	0.179	0.013	106.8	0.002	0.024	0.141	0.016	129.8	0.002	0.032	0.069	0.004	90.5	0.005	0.044	0.071	0.008
107	0.4	0.1	0.4	59.3	0.084	0.138	0.071	0.027	154.2	0.071	0.142	0.054	0.041	152.7	0.084	0.133	0.050	0.025	187.1	0.087	0.134	0.034	0.022
109	0.6	0.1	0.8	4.5	0.133	0.213	0.060	0.014	30.7	0.105	0.170	0.073	0.018	70.4	0.136	0.181	0.068	0.012	36.6	0.122	0.183	0.045	0.011
117		0.1	0.4	71.8	0.002	0.035	0.092	0.363	120.8	0.000	0.018	0.083	0.433	96.6	0.000	0.028	0.085	0.354	121.5	0.000	0.025	0.067	0.350
119		0.1	0.8	58.0	0.000	0.023	0.057	0.645	90.8	0.000	0.017	0.061	0.541	72.0	0.000	0.020	0.055	0.519	128.5	0.000	0.024	0.053	0.481
91		0.4		57.6	0.000	0.030	0.203	0.005	114.7	0.000	0.026	0.181	0.014	84.5	0.005	0.024	0.114	0.005	90.6	0.005	0.044	0.101	0.005
111	0.2	0.3		93.7	0.028	0.074	0.180	0.007	76.2	0.031	0.077	0.123	0.017	140.9	0.046	0.084	0.088	0.011	120.3	0.040	0.076	0.086	0.011
121		0.3	0.2	66.1	0.002	0.023	0.194	0.204	138.0	0.000	0.019	0.175	0.182	9.3	0.005	0.024	0.140	0.135	88.3	0.000	0.038	0.128	0.131
93		0.8		0.0	0.000	0.031	0.314	0.009	97.1	0.000	0.025	0.273	0.013	89.5	0.016	0.031	0.217	0.008	127.5	0.000	0.037	0.210	0.011
113	0.2	0.6		32.8	0.020	0.067	0.342	0.006	45.3	0.020	0.056	0.197	0.016	50.3	0.038	0.071	0.235	0.009	160.8	0.039	0.074	0.165	0.007
123		0.6	0.2	5.9	0.002	0.027	0.388	0.178	53.6	0.000	0.021	0.340	0.159	35.1	0.002	0.022	0.247	0.134	98.1	0.000	0.033	0.239	0.128
115	0.6	0.6		10.8	0.089	0.162	0.395	0.016	6.4	0.103	0.145	0.413	0.018	13.4	0.104	0.153	0.387	0.011	42.8	0.092	0.147	0.381	0.010
125	0.6	0.6	0.6	9.2	0.000	0.024	0.321	0.450	22.7	0.000	0.015	0.358	0.475	20.0	0.000	0.019	0.318	0.382	81.7	0.000	0.028	0.268	0.429

THREE-SALT TREATMENTS

In the three-salt combinations shown in table 5 the toxic load becomes great enough to produce toxicity in the four crops in all but a few of the weaker concentrations. The additions of 0.2 per cent sodium carbonate, 0.1 per cent sodium chloride, and 0.2 per cent sodium sulfate are made the basis for comparison. Groupings are made in which two salts remain constant and one is made variable. These are also compared with similar two-salt combinations presented in tables 2, 3 and 4, for the effect of the unit additions to the two-salt combinations. A comparison of the basic treatment with the two-salt combinations discussed before, shows that the yield is higher in crop 1 than would be expected from the additive effects of the three salts, lower in crop 2, and approaches what might be expected in crops 3 and 4.

When the concentrations of 0.1 per cent sodium chloride and 0.2 per cent sodium sulfate remain constant and the carbonate addition is doubled, we note increased toxicity in crop 1 and increased stimulation in the remaining crops. Adding more than 0.4 per cent sodium carbonate prevents crop growth in this combination of the three salts.

Increasing the sodium sulfate content to 0.4 per cent results in a stimulation in crops 2 and 3, and a drop to 11 per cent below normal in crop 4; 0.8 per cent sodium sulfate reduces the yield in all crops, with partial recovery in crop 4, which shows a yield of 86 per cent of normal.

Treatments 18 and 31 are similar to 145 and 25 except that they have a 0.2 per cent sodium chloride addition instead of 0.1 per cent. In spite of this slight difference the former is highly toxic throughout the four crops. Treatments 34 and 43 correspond to 18 and 31 except that the chlorides have been increased to 0.4 per cent. The yield is reduced comparatively little because of this change, the major reduction occurring in the increase from 0.1 to 0.2 per cent sodium chloride.

In treatments 34 and 43 there is a simultaneous increase in two salts over the basic treatment, giving concentrations of 0.4 per cent sodium carbonate, 0.4 per cent sodium chloride, and 0.2 per cent sodium sulfate in 34, and 0.2 per cent sodium carbonate, 0.4 per cent sodium chloride, and 0.4 per cent sodium sulfate, in 43. This results in heavy reduction below normal. It is to be observed that there is an increase of sodium chloride in each case. In treatment 75, 0.4 per cent sodium carbonate, 0.1 per cent sodium chloride, and 0.4 per cent sodium sulfate, there is no increase in chloride content. The decrease in crop yield is not so great as in 34 and 43, but in this case the yield is only 63 per cent of normal in crop 4.

The effect of an additional salt added to the two-salt combinations, is a general trend toward additive toxicity that is not in proportion to the amount or kind of salt added. Treatment 145, which varies from 133 by the addition of 0.1 per cent sodium chloride, shows very little difference in yield, although in 18, which varies from treatment 133 by the addition of 0.2 per cent sodium chloride, there is a high toxicity for all crops. On the other hand, treatment 25

TABLE 5

Soil treatments, salt recovery and crop yield
Three-salt combinations

NUMBER	TREATMENT Na₂CO₃ per cent	TREATMENT NaCl per cent	TREATMENT Na₂SO₄ per cent	FIRST CROP Yield per cent	FIRST CROP Na₂CO₃ per cent	FIRST CROP Total Na₂CO₃ per cent	FIRST CROP NaCl per cent	FIRST CROP Na₂SO₄ per cent	SECOND CROP Yield per cent	SECOND CROP Na₂CO₃ per cent	SECOND CROP Total Na₂CO₃ per cent	SECOND CROP NaCl per cent	SECOND CROP Na₂SO₄ per cent	THIRD CROP Yield per cent	THIRD CROP Na₂CO₃ per cent	THIRD CROP Total Na₂CO₃ per cent	THIRD CROP NaCl per cent	THIRD CROP Na₂SO₄ per cent	FOURTH CROP Yield per cent	FOURTH CROP Na₂CO₃ per cent	FOURTH CROP Total Na₂CO₃ per cent	FOURTH CROP NaCl per cent	FOURTH CROP Na₂SO₄ per cent
143	0.2	0.1	0.2	100.6	0.030	0.077	0.086	0.219	112.5	0.042	0.080	0.058	0.153	120.5	0.038	0.090	0.043	0.118	107.9	0.031	0.082	0.054	0.132
145	0.4	0.1	0.2	50.4	0.091	0.140	0.060	0.132	151.0	0.073	0.143	0.058	0.121	148.5	0.118	0.175	0.035	0.093	129.9	0.081	0.139	0.063	0.077
147	0.6	0.1	0.2	1.2	0.156	0.210	0.089	0.161	12.1	0.125	0.202	0.071	0.120	2.1	0.107	0.190	0.065	0.114	30.6	0.118	0.173	0.059	0.097
79	0.8	0.1	0.2	7.8	0.248	0.294	0.073	0.206	0.0	0.165	0.265	0.049	0.065	0.0	0.214	0.268	0.068	0.075	0.0	0.140	0.262	0.056	0.061
25	0.2	0.1	0.4	102.8	0.024	0.069	0.091	0.389	140.8	0.031	0.072	0.049	0.386	175.0	0.035	0.078	0.068	0.317	89.7	0.018	0.070	0.059	0.323
2	0.2	0.1	0.8	77.3	0.015	0.059	0.087	0.729	24.2	0.018	0.049	0.079	0.640	69.8	0.002	0.044	0.079	0.688	86.3	0.016	0.050	0.086	0.655
4	0.2	0.4	0.2	67.5	0.026	0.072	0.333	0.166	0.6	0.015	0.047	0.361	0.184	21.4	0.005	0.047	0.315	0.169	57.2	0.016	0.055	0.287	0.157
12	0.2	0.6	0.2	43.3	0.020	0.080	0.222	0.133	47.9	0.023	0.058	0.380	0.134	40.0	0.008	0.050	0.372	0.151	56.5	0.018	0.056	0.180	0.151
18	0.4	0.2	0.2	0.0	0.068	0.121	0.196	0.194	31.2	0.059	0.122	0.197	0.177	56.4	0.063	0.110	0.188	0.198	41.4	0.061	0.114	0.150	0.192
31	0.2	0.2	0.6	28.1	0.018	0.060	0.191	0.496	23.5	0.018	0.057	0.192	0.420	34.5	0.018	0.058	0.165	0.468	28.9	0.007	0.045	0.160	0.503
34	0.4	0.4	0.2	14.5	0.052	0.112	0.347	0.177	19.8	0.041	0.093	0.407	0.188	23.5	0.041	0.097	0.393	0.187	28.1	0.046	0.091	0.318	0.179
43	0.2	0.4	0.4	20.6	0.015	0.058	0.363	0.337	11.8	0.016	0.052	0.348	0.343	3.2	0.012	0.052	0.362	0.343	14.4	0.013	0.043	0.330	0.357
75	0.4	0.1	0.4	30.5	0.069	0.115	0.141	0.308	46.3	0.060	0.119	0.138	0.293	62.8	0.074	0.131	0.118	0.254	63.0	0.075	0.112	0.109	0.236

with the addition of 0.1 per cent sodium chloride shows improvement over 127 in crops one and three, but 31, with an addition of 0.2 per cent sodium chloride to the salts present in 127, produces heavy toxicity throughout. Treatment 2, in which 0.1 per cent sodium chloride is added to that present in 129 or 131, shows lower toxicity in crop 1. Similarly, the addition of 0.2 per cent sodium carbonate in 12 over the treatments in 123 shows decreased toxicity in crop 1. A comparison of 12 and 113, shows an addition of 0.2 per cent sodium sulfate to the two-salt treatment. This is the only case in which the addition of sodium sulfate to the two-salt combination decreases the toxicity in crop 1. Treatment 25 is the only one in the entire series which shows a stimulation above the untreated check in crop 1. These cases show evidence of antagonism of ions in crop 1. They do not persist in the three succeeding crops.

GERMINATION DATA

In order to simulate field conditions an attempt was made to germinate the oats without addition of water other than that originally present in the soil. This was not successful in view of the fact that two very hot days dried the soil too rapidly, killing some of the young grain. This drying was more marked in the check soils and in the low salt treatments. In some of the heavy salt treatments, the salts seemed to retard evaporation, consequently these salt treatments showed a higher germination than the check soils. For this reason data on germination in crop 1 are not a true index of the influence of salt on germination. A perfect germination in crop 1 would appear in the table as 208 per cent. Although the germination in all treatments was low, there was a sufficient number of plants in all pots to continue the experiment without replanting the series. The influence of salt treatments on germination is more clearly shown in crops 2, 3, and 4, since during germination conditions were kept as favorable as possible by daily additions of small amounts of water.

Sodium carbonate additions appear to depress germination slightly in crops 2 and 3 and to approach normality in crop 4. The same general trend is evident with sodium chloride except that the highest treatment shows a little greater toxicity toward germination than sodium carbonate.

Sodium sulfate appears to have little effect on germination of oats, except in the highest concentration employed, namely, 2.4 per cent.

In the two-salt treatments similar characteristics are apparent, except that the effect on germination of oats is greater when the total salt addition is composed of the two salts than when similar concentrations consist entirely of individual salts. This is especially true where sodium chloride forms a part of the combination. Sodium carbonate with sodium chloride, or sodium sulfate with sodium chloride produces a greater decrease in germination than similar amounts of sodium carbonate and sodium sulfate, or of either salt alone.

There appears to be a more marked decrease in germination in the three-salt combinations than in the two- and one-salt treatments. Here again the

TABLE 6

Germination and grain yield expressed as per cent of the check

NUMBER	GERMINATION				GRAIN	
	First crop	Second crop	Third crop	Fourth crop	Second crop	Fourth crop
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
135	100	100	100	100	100.0	100.0
81	96	83	91	94	48.6	95.0
83	122	75	95	106	16.2	56.4
85	157	83	95	106	5.4	45.8
87	130	75	55	124	0.0	0.0
89	113	88	95	106	100.0	98.0
91	130	88	95	124	51.4	104.7
93	104	67	41	100	0.0	74.7
95	96	92	100	82	70.3	120.5
97	122	88	100	70	121.5	124.5
99	96	92	100	112	102.6	131.7
101	96	96	91	94	46.0	217.6
103	113	92	85	100	65.0	143.9
105	104	38	45	112	67.6	42.5
107	148	96	77	76	129.6	215.0
109	139	71	100	141	8.1	83.8
111	165	100	100	106	116.2	145.7
113	78	33	77	100	65.0	106.4
115	122	58	32	59	21.6	22.5
117	104	100	95	106	100.0	133.7
119	113	92	100	82	89.3	150.5
121	96	83	95	76	78.4	103.3
123	96	46	36	82	0.0	101.1
125	96	17	18	76	2.7	86.0
127	113	88	82	100	178.3	93.5
129	148	88	100	100	151.3	93.7
131	148	100	82	124	53.6	102.7
133	122	88	95	112	29.7	47.5
137	130	83	100	112	25.4	2.9
139	96	88	50	76	0.0	0.0
141	148	96	68	106	5.4	26.6
143	157	100	91	94	173.0	118.0
145	122	92	100	94	108.0	153.2
147	148	92	95	124	0.0	21.1
79	113	100	100	118	0.0	38.2
25	104	96	100	112	143.2	91.0
2	96	92	77	124	51.3	100.0
4	139	46	14	82	148.5	58.7
12	113	38	41	112	54.2	56.7
18	113	88	55	135	0.0	53.6
31	70	63	59	118	43.3	23.6
34	139	54	23	82	8.1	30.3
43	165	38	32	96	10.8	12.9
75	130	100	91	118	56.8	38.8

influence of chlorides is marked where it constitutes a major portion of the salt concentrations. The soils seem to have recovered from the effects of the treatment in the fourth crop to the extent that germination approaches normal in all concentrations.

GRAIN YIELDS

As mentioned earlier in this discussion, climatic conditions were favorable for the development of grain in crops 2 and 4.

Single additions of sodium carbonate appear to be very destructive to grain yields in crop 2 and slightly less so in crop 4. The amount of reduction in grain yield is in direct proportion to the amount of salt added to the soil.

Additions of sodium chloride appear to be less toxic to grain production than additions of sodium carbonate. Even in the highest addition in crop 4, a 74 per cent normal grain yield was secured.

In the three highest sodium sulfate treatments, grain yield is reduced approximately 50 per cent. In all the remaining concentrations sodium sulfate additions stimulate grain production. This is especially noticeable in crop 4.

In the two-salt combinations each salt maintains its own characteristic influence on grain production. High carbonates in combination with chlorides or sulfates produce a marked toxicity. If, however, either the chlorides or sulfates predominate over the carbonates, grain production is stimulated. Sulfates continue to stimulate grain production at much higher concentrations than chlorides.

A total concentration of 1.0 per cent added salt approaches the upper limit of tolerance for grain production in either a two- or three-salt combination. In the three-salt treatments, a given concentration of total salts seems more detrimental to grain yield than to the total weight produced. Any concentration of combined salts, except where sodium carbonate is the greatly predominating salt, seems less toxic to grain yield than the same concentration of one of the salts alone.

SUMMARY

1. Four crops of oats were grown in the greenhouse on Idaho soil treated with various concentrations of a single alkali salt together with various combinations of salts. The salts used were sodium carbonate, sodium chloride and sodium sulfate.

2. Toxicities of the salt applications varied with the successive crops. In general, regardless of the type of treatment, additions of salts were most toxic to the first crop. The majority of the salt treatments showed a stimulated yield of oats in the second crop, which was not maintained in the third crop. Fourth crop yields, where the salt concentration was not too excessive, showed a tendency of the soil to produce crops approaching normal.

3. Sodium carbonate additions above 0.4 per cent, which gave 0.15 per cent recoverable carbonates, proved toxic to oats.

4. The toxic concentration of sodium chloride was between 0.2 and 0.3 added salt or 0.17 to 0.2 recoverable salt for oats.

5. Sodium sulfate in concentrations as high as 1.5 per cent did not appear to be toxic to oats except in the first crop.

6. Low additions of sodium chloride and sodium sulfate, when added to a basic treatment of 0.2 to 0.4 per cent sodium carbonate usually showed increased yields over the basic single sodium carbonate additions. These data support, in a measure, the phenomena that has been called "antagonism of anions."

7. Oats tolerate rather high concentrations of the combined alkali salts, when the total salt content consists of a low concentration of each salt.

8. Papers I to IV of this series have been primarily presentation of data in connection with the tolerance studies conducted at this station. A fifth paper is being prepared in which an attempt will be made to discuss some of the theoretical and practical considerations arising from these studies.

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PLATE 1

REPRESENTATIVE POTS SHOWING COMPARATIVE GROWTH FOR THE FOUR CROPS OF OATS

The numbers on the pots correspond to the numbers of treatments reported in the tables of the text, even numbers being duplicates of the odd numbers just preceding.

FIG 1. First crop.
  136—check
  82—0.2 per cent Na_2CO_3
  83—0.4 per cent Na_2CO_3
  85—0.6 per cent Na_2CO_3

  89—0.2 per cent NaCl
  91—0.4 per cent NaCl
  94—0.8 per cent NaCl

FIG. 2. Second crop.
  135—check
  81—0.2 per cent Na_2CO_3
  83—0.4 per cent Na_2CO_3

  85—0.6 per cent Na_2CO_3
  89—0.2 per cent NaCl
  94—0.8 per cent NaCl

FIG. 3. Third crop.
  136—check
  81—0.2 per cent Na_2CO_3
  83—0.4 per cent Na_2CO_3

  85—0.6 per cent Na_2CO_3
  89—0.2 per cent NaCl
  94—0.8 per cent NaCl

FIG. 4. Fourth crop.
  136—check
  81—0.2 per cent Na_2CO_3
  83—0.4 per cent Na_2CO_3

  86—0.6 per cent Na_2CO_3
  89—0.2 per cent NaCl
  94—0.8 per cent NaCl
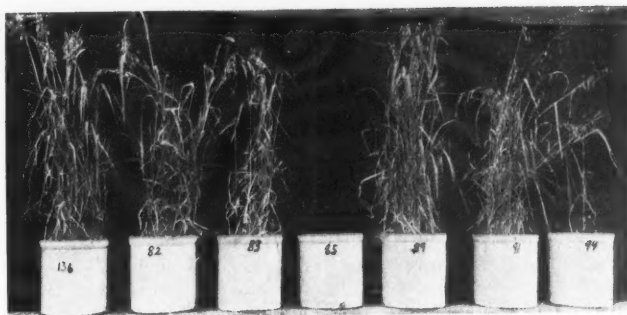
Fig. 1
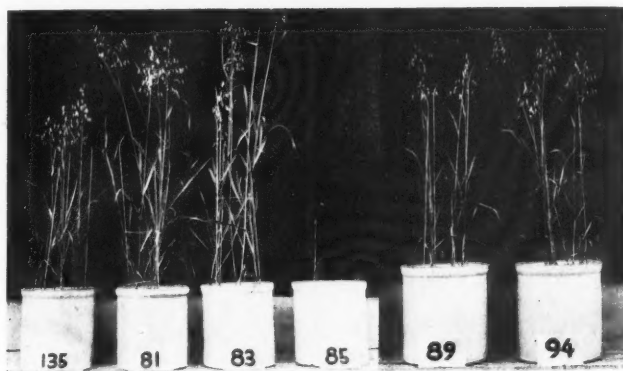
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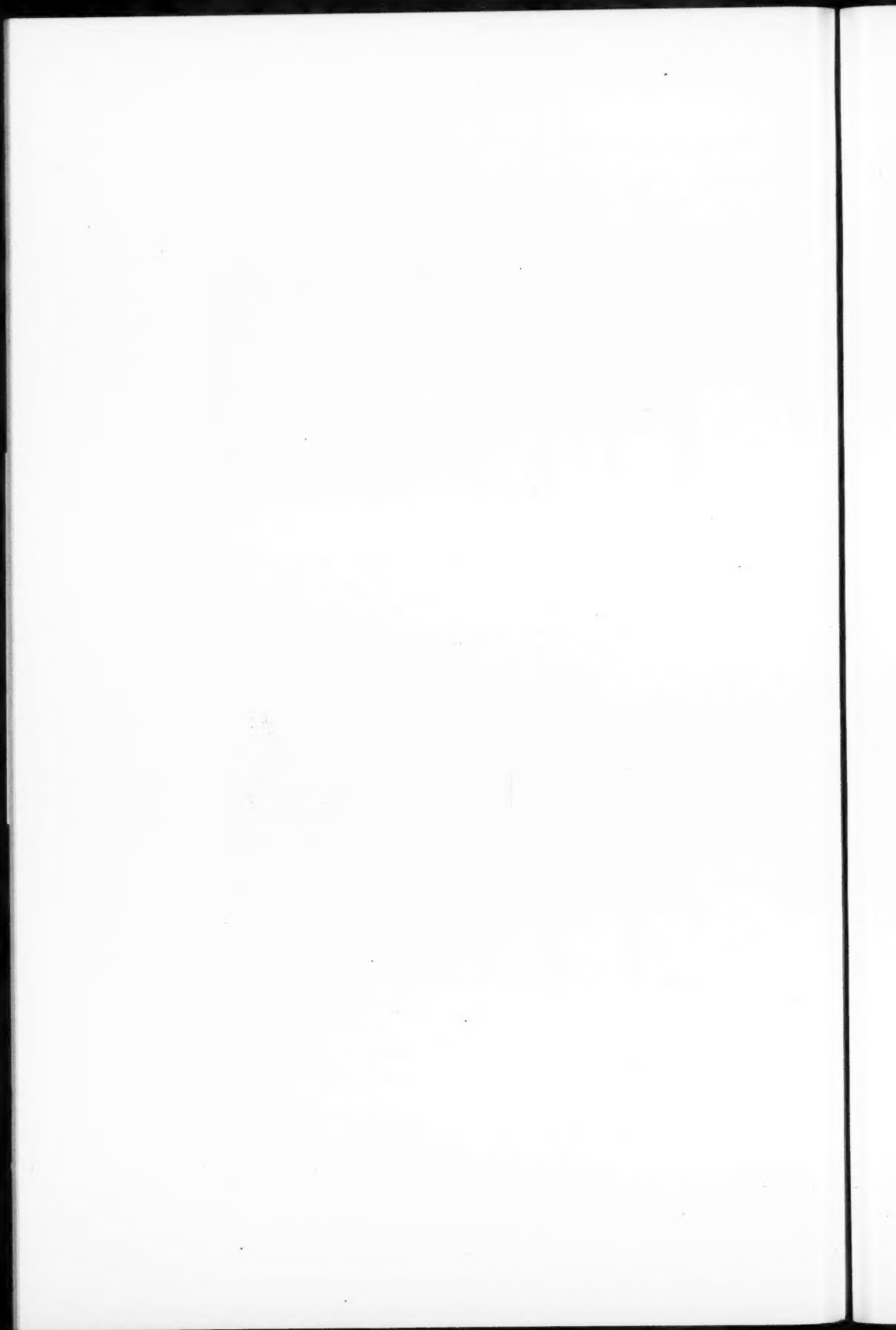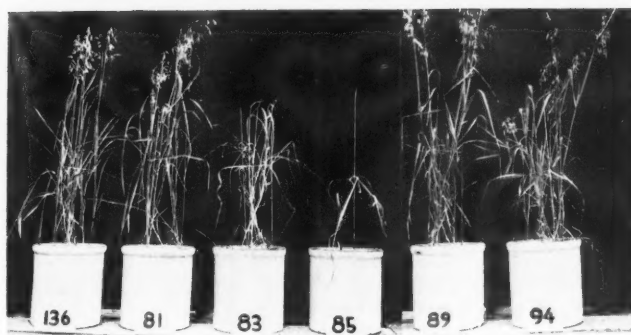
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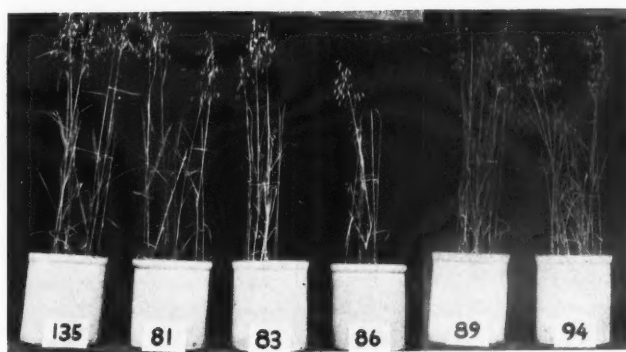
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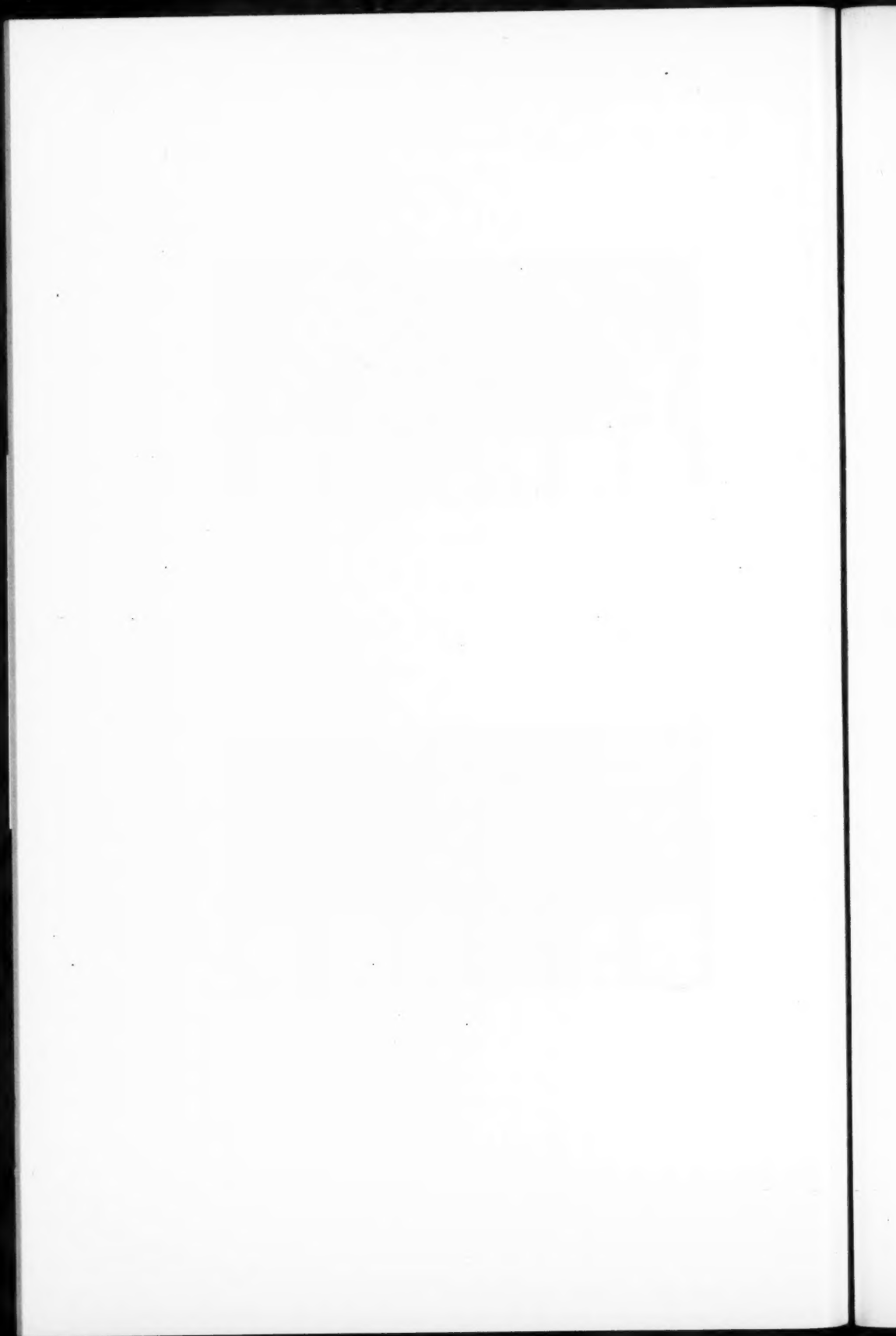
THE RATE OF OXIDATION OF DIFFERENT FORMS OF ELEMENTAL SULFUR

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Sulfur transformation in the soil has been long known but not until recent years has the process of oxidation been investigated.

The fact that a small amount of sulfur is oxidized in a sterilized soil as compared with the quantity of sulfates derived from elemental sulfur in an unsterilized soil has given an impetus to the study of the biological phase of the process (13). Bernard stated that the control of the potato scab was due to the disinfection of the soil by sulfur. Brown and Kellogg (4) attributed the formation of sulfates from elemental sulfur to factors of a biological nature. The amount of the sulfates varied for different soils, hence these workers applied the term "sulfofying power" (5). Lipman (9) and his associates have shown that elemental sulfur is oxidized by proper bacteria. Several types of sulfur bacteria have been isolated and this process of oxidation has been confirmed.

The control of the potato scab by inoculated sulfur is superior to that of uninoculated sulfur as reported by Martin (12) and others of the New Jersey Station.

Lyon and Bizzell (11) questioned the advisability of applying sulfur to soil to stimulate plant growth, for their findings show that losses of sulfur by drainage water from cropped and uncropped lysimeters were nearly the same when the sulfates removed by the crops were considered.

That the cultivation of an unfertilized silt loam for 16 years has reduced the total sulfur supply is also reported by Ames and Boltz (2) of this Station.

Reimer and Tartar reported that sulfur (15) applied with fertilizers on Oregon soils gave increases of alfalfa. Tottingham and Hart attributed the increase of clover on a loam soil to sulfur and questioned this increase on other soils. The number of nodules on red clover has been increased on Missouri soils by sulfur and gypsum, as reported by Duley.

Miller reports that the stimulation of the soil flora has been attributed to an application of 400 pounds of elemental sulfur. This author finds the nitrogen content and the number of nodules on red clover to have increased where sulfur has been applied. There seems to be evidence that sulfur has been a factor in crop increases. Certain conditions within the soil have influenced the soil flora.

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As the oxidation of sulfur increases the acidity, other elements may be liberated directly or indirectly as a result of other salts formed.   The liberation of potassium is brought about by the formation of salts rather than by the direct action of acidity on the insoluble potassium compounds in the soil. Calcium is readily soluble.   Iron and aluminum are in great abundance where sulfur is oxidized in an acid silt loam soil, as compared to small amounts in the presence of a calcium carbonate soil or a highly buffered basic clay, concludes Ames and Boltz (3).

Using green-sand sulfur composts Rudolfs (15) concludes that potassium is made available at a hydrogen-ion concentration of 2.7 to 2.3.   Soybeans growing in culture using green-sand as a source of potassium matured earlier and had a larger yield of beans than those soybeans getting potassium from potassium phosphate.   Hence the crop increases may be due to the liberation of plant-foods by the acidity from the oxidation of the sulfur and also to such soil conditions as inhibit the growth of parasitic organisms.

In several investigations different kinds of sulfur have been compared. Halverson and Bollen (6) applied sulfur to 14 types of Oregon soils.   An application of 100 pounds of flour of sulfur per acre was compared with an equivalent amount of inoculated sulfur.   The relative oxidizing power or "sulfofying power" of these soil types was not greatly altered by the use of inoculated sulfur.   For some types the inoculated sulfur was more completely oxidized than the flour of sulfur.   However, as all the soils oxidized the flour of sulfur readily the use of inoculated sulfur seemed unnecessary.

The oxidation of sulfur in other soils, which gave such crop yields as 1000 per cent increase, as reported by Reimer, was investigated by Joffe and McLean (8).   Here the authors compared inoculated sulfur with uninoculated in composts equivalent to an application of 1 ton per acre-foot.   On the light soils, in 15 days a hydrogen-ion concentration of 5.4 to 5.2 was reached, which was too high for alfalfa; an application of 600 to 700 pounds may be too much for soils that are slightly buffered.   The authors conclude that inoculated sulfur is more readily oxidized.

Adams (1) applied sulfur on a Miami silt loam soil at the rate of 1500, 2000, and 3000 pounds per acre, and incubated the composts for 30 days.   The hydrogen-ion concentration increased from 4.75 to 3.62, and 3.16, respectively. After reaching a certain hydrogen-ion concentration a slight increase had a decided effect upon the plant.   A fair growth of clover continued in the soil at 3.5 but no growth occurred at 3.4, whereas in the sand checks a fair growth occurred at 4.3 but none at 4.1.   The fact that growth ceased at 4.1 in the sand, and clover grew at 3.5 in the soil, indicates that the acidity at which a plant will grow is a property of the soil and not entirely of the plant.   This property varies with the soil used.   The author further states that there was a corresponding increase in soluble material in the soil because of the oxidation of the sulfur, as determined by freezing point methods.

The earlier experiments have shown that for a soil the sulfofying power is

inherent; that is, a capacity of its bacterial flora, particularly adapted to the conditions *in situ*, for oxidizing elemental sulfur. The introduction of sulfur bacteria has not interfered with this power and in some instances has increased the amount of sulfur oxidized. Rapid oxidation occurs in the presence of bases. On the other hand a certain hydrogen-ion concentration limits the growth in light soils slightly buffered.

In a soil type low in organic matter but well buffered with lime, the maximum hydrogen-ion concentration would not inhibit the oxidation of sulfur before average field applications could be oxidized. A certain kind of sulfur would be oxidized in a definite time, the sulfate end-products being a measure of the quantity of sulfur oxidized. Also the different characteristics of one kind of sulfur would influence the rate of oxidation. The amount oxidized for a common interval of time, depending upon the surface and the nature of the manufacture, would be a comparison for the relative values of different forms of sulfur for a certain soil.

TABLE 1

The percentage of sulfur passing sieves, in mesh per linear inch

KIND OF SULFUR	100-MESH	200-MESH
	per cent	*per cent*
Ground flour..	90.3	37.8
Superfine bolted......................................	99.2	89.0
Commercial flowers...................................	90.2	50.2
Inoculated sulfur.....................................	89.9	47.7

With these statements in mind this experiment was made to determine the relative values of forms of commercial sulfur in controlled incubation tests, using amounts of sulfur practically adapted to field applications.

The kinds of sulfur used in this work are those obtained easily and are the common forms applied alone or with fertilizers in field culture. Two flours of sulfur of different fineness were used to compare the effect of surface on the quantity of sulfates oxidized: the one, a superfine bolted, is used extensively for dusting purposes; the other represents the total unseparated product as it comes from the mill. Flowers of sulfur afforded the comparison of sublimed particles with those of ground flour. Inoculated sulfur was included to determine if additional sulfur bacteria were necessary for this soil. Ammonium sulfate was also included in the test to determine the reaction on the soil at the same time.

The relative fineness of the several grades of sulfur is shown in table 1.

THE SOIL

The soil, which had been limed, was taken from several unfertilized plots of the 5-year fertility rotation at Wooster Station. During the long period of cultivation the total sulfur content had been reduced. A sufficient quantity

of this soil was secured in the latter part of the growing season and was never allowed to dry out. As far as the biological processes are concerned, the conditions of storage kept this soil normal. At the time of storage in a greenhouse this soil was passed through a 12-mesh sieve and kept free from contamination until it was used.

THE METHOD

Sufficient soil for this test was thoroughly mixed, and 200 gm. were placed in pint mason jars. An application of each kind of sulfur at the rate of 500 pounds an acre was made on each duplicated series. The sulfur was thoroughly mixed with the soil in each jar, and sufficient distilled water was added to bring the moisture content up to 50 per cent of the moisture-holding capacity. One series received ammonium sulfate in solution at the rate of 100 pounds an acre. Distilled water was added to this series to bring it to the same moisture content as those receiving sulfur. After a day the contents of the jars were stirred and brought to good physical condition. The caps were replaced to prevent undue evaporation. At regular intervals sufficient distilled water was added to compensate for the loss by evaporation and the contents were brought to good physical condition. At all times care was taken to prevent contamination and at no time were the jars sealed. All series were incubated at nearly uniform temperatures.

ANALYTICAL METHODS

At the conclusion of each period of incubation the entire portion of the jar was extracted with previously boiled distilled water and diluted to 1:5. After being shaken for 4 hours the extract was filtered through a Büchner funnel, and an aliquot of 400 cc. of the clear filtrate, representing 85.4 gm. of dry soil was taken for each determination of sulfates.

The sulfates remaining after those from the respective soil checks are deducted, represent the elemental sulfur oxidized for the period. The rate of oxidation for each kind of sulfur is shown by the increase of the sulfates for each series. The hydrogen-ion concentration was made colorimetrically on each filtrate and recorded for each period of incubation.

The weight of sulfur oxidized per acre and the pH for each period are shown in table 2.

DISCUSSION

As the quantity of sulfur in the incubated soil mixtures was in the same ratio as the applications per acre in the field, the amounts of sulfur oxidized and the rates of oxidation in both instances would be similar. There was a gradual oxidation of all kinds of sulfur throughout the entire experiment with the exception of the superfine-bolted sulfur, which was slightly more completely oxidized at the sixth week than at the eighth week. What caused the reduction in sulfates or inhibited the biological processes was not determined.

A marked difference in the completeness of oxidation is shown at the end of the eighth week by these percentages:

Kind of sulfur	per cent oxidized
Ground flour	48.88
Superfine bolted flour	89.22
Commercial flowers	70.32
Inoculated sulfur	33.66

There is no doubt that all the kinds of sulfur would have been more completely oxidized if the experiment had been continued. The hydrogen-ion concentration increased slightly after the second week, hence the biological processes could not have been inhibited and oxidation should have proceeded, as the soil had been limed. The pH of the superfine bolted flour, which was the most completely oxidized, was highest for the eighth week. As the pH of the other kinds of sulfur had not reached this concentration they should have continued to oxidize.

TABLE 2

The total sulfur oxidized and the pH for each week by period

APPLICATION PER ACRE	TIME											
	First week		Second week		Third week		Fourth week		Sixth week		Eighth week	
	pounds	pH	pounds	pH	pounds	pH	pounds	pH	pounds	pH	pounds	pH
No treatment	21.0	7.3	19.4	6.9	19.4	6.9	20.0	6.9	19.4	7.0	19.4	6.9
500 pounds ground flour	70.4	7.1	104.6	6.9	134.4	6.7	193.0	6.7	236.4	6.7	263.2	6.5
500 pounds superfine bolted	103.0	7.1	207.2	6.6	294.0	6.4	326.0	6.3	476.0	6.3	465.0	6.1
500 pounds commercial flowers	87.6	7.1	154.4	6.7	217.6	6.7	266.4	6.7	346.0	6.7	369.8	6.5
500 pounds inoculated sulfur	48.0	7.2	66.0	6.9	88.0	6.9	128.2	6.8	156.4	6.7	187.6	6.6
100 pounds ammonium sulfate	44.8	7.1	44.0	6.9	42.8	6.9	42.4	6.9	42.8	6.9	43.4	6.9

The fineness of the kinds of sulfur is a factor in the rate of oxidation. Therefore that kind having the most surface exposed to the soil will be most completely oxidized. Also the character of the surface of a sublimed particle of sulfur is different from that of a ground one, but as the experiment was of short duration this specific difference is not an important factor. A comparison of table 1, giving the proportions of the sulfurs that pass 200-mesh, with the percentages of sulfur oxidized, shows the importance of the factor of fineness. The whole amount of the sulfur oxidized from the superfine bolted may be accounted for in this 200-mesh portion. The flowers of sulfur required in addition to this 200-mesh portion for all the sulfur oxidized, a small amount of the 100-mesh size. The ground sulfur required a still larger amount of 100-mesh sulfur, as well as all of the 200-mesh, to account for the quantity oxidized. As inoculated sulfur was oxidized less than the other three kinds, the additional sulfur bacteria were unnecessary for this soil. Inoculated sulfur did not require all the 200-mesh sulfur to account for the quantity of sulfur oxidized.

It was noted that part of the inoculated sulfur was insoluble; one would suspect that not all of this 200-mesh portion was sulfur, hence this was not oxidized as well as the 100-mesh sulfur. The small quantity of sulfur oxidized might be due to the dilution of the finer portions through its process of manufacture.

The reaction between ammonium sulfate and the soil was complete within the first week, the pH as well as the sulfates remaining the same throughout the experiment. The untreated soil showed slight change in the pH after the first week. There were no sulfates from the oxidation of organic sulfur compounds in the soil.

In another instance flowers of sulfur was incubated with a basic clay soil. The percentages of the total amount of sulfur oxidized are recorded in table 3.

The elemental sulfur recovered by extraction with acetone was 18.8 per cent for the 4-week period and 12.3 per cent for the 8-week period. As this sulfur was oxidized, this method fairly checks the total sulfur oxidized by the method used in this work. This basic clay soil has a higher "sulfofying power" than the Wooster silt loam, hence the inoculated sulfur would not be necessary for this soil. On a field test of this basic clay soil, flowers of sulfur had entirely oxidized during the growing season.

TABLE 3

Sulfur oxidized by a basic clay soil

APPLICATION	TIME OF OXIDATION	
	4 weeks	8 weeks
	per cent	*per cent*
0.2 gm. per 300 gm. soil.............................	81.1	86.8

CONCLUSION

Four commercial sources of elemental sulfur were incubated in one common silt loam soil. Flowers of sulfur were incubated in two widely different soil types, containing sulfur bacteria capable of oxidizing elemental sulfur. The basic clay soil has a higher "sulfofying power" than the limed Wooster silt loam.

The rate of oxidation of the different forms of sulfur is dependent upon the surface or fineness. The most complete oxidation was correlated with the highest hydrogen-ion concentration. The water-soluble sulfates increased with slight increases of hydrogen-ion concentration. The reaction of ammonium sulfate within the soil was completed within the first week. Throughout the entire period of incubation after the first week the hydrogen-ion concentration remained practically constant for the untreated soil. The sulfates from the untreated soil indicated that there was practically no sulfur contributed from organic sources. The acetone extraction method is a direct check on the oxidation process.

The method of incubation of different forms of sulfur in a common soil under controlled conditions affords comparative estimation of the values of different forms of elemental sulfur.

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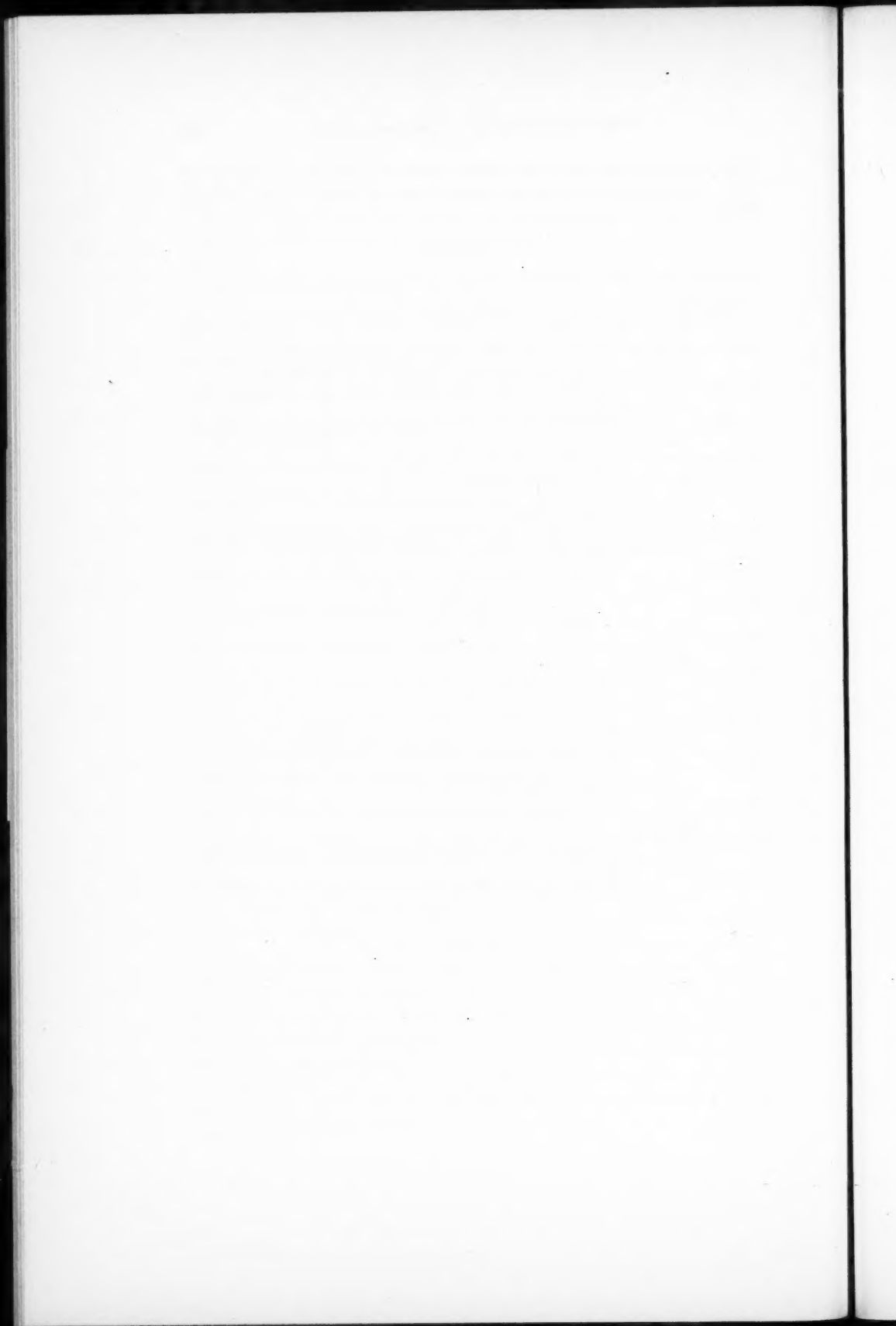
VARIATIONS IN THE MINERAL CONTENT OF CABBAGE AND SAUERKRAUT[1]

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Variations in the mineral content of plant material have been noted by Beal (1), Wheeler and Hartwell (15), Forbes (3), and Hoagland (4). It was found that these elements varied with the type of soil and with the fertilizer used on the soil. As an example of the effect of fertilizers the results obtained by Wheeler and Hartwell with the white radish may be taken. The unlimed plants averaged 1.14 per cent CaO; the once-limed, 1.21 per cent; and the thrice-limed, 1.70 per cent. Forbes found that some samples of bluegrass contained more than three times as much calcium as other samples. He also reported a considerable increase of both calcium and phosphorus in the grass when the soil was fertilized with lime and phosphates.

The importance of an adequate supply of calcium, phosphorus, and iron in the diet is receiving increasing attention from investigators in the field of nutrition. Calcium and phosphorus are of particular importance because of their close relation to the antirachitic factor and it is not improbable that iron plays an even more important rôle in nutrition than has hitherto been assigned to it. In discussing the question of a supply of these elements, Sherman (13) advocates an allowance of at least 50 per cent above the requirement as a margin of safety. In calculating the mineral content of food from published tables of analyses, this margin of safety may disappear if consideration is not given to losses incurred in the preparation of the food and to the variations in the mineral content of vegetables grown in different localities.

It is improbable that any existing table of analyses is more than a very rough approximation of the percentage of calcium, phosphorus, and iron in any given sample. In some cases such figures are based on the analyses of two or three samples all of which may have been grown on the same type of soil. It would add much to our confidence in these tables if the number of analyses were given as well as the percentage figure.

As an example of this paucity of analytical data, cabbage may be taken. In a review of the calcium, phosphorus, and nitrogen content of plant materials Parker and Truog (9) give only one reference to the calcium content of cabbage.

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A further careful search of the literature has resulted in the finding of only two other papers (2, 12) which give the percentage of calcium in cabbage. The data for other mineral elements are likewise meagre. Only rarely can more than three or four reports dealing with any given element be found. Because of this lack of data it was decided to analyze a number of samples of cabbage obtained from New York, Ohio, Illinois and Wisconsin. These samples were obtained for the purpose of studying the composition of cabbage in relation to its kraut-making qualities. An opportunity was thus afforded to determine the calcium, phosphorus, and iron content of sauerkraut and the loss of these elements in the manufacture of this food product.

TABLE 1

Tabular description of cabbage and sauerkraut

SAMPLE NUMBER	CABBAGE				SAUERKRAUT	
	Source	Date of harvest	Variety	Quality	Age	Quality
					days	
318	Ohio	August 21	Copenhagen	Good	41	Fair
322	Ohio	September 17	Copenhagen	Good	33	Fair
324	Wisconsin	September 29	Hendrickson Early	Good	25	Fair
325	Wisconsin	September 29	Hendrickson Early	Poor	25	Poor
326	Illinois	October 1	All seasons	Fair	33	Good
328	Wisconsin	October 4	Copenhagen	Poor	31	Fair
329	Wisconsin	October 7	All seasons	Excellent	31	Good
330	Wisconsin	October 8	Copenhagen	Good	33	.....
331	Wisconsin	October 8	Succession	Good	33	.....
332	Ohio	October 10	All seasons	Excellent	33	Excellent
333	Wisconsin	October 24	All seasons	Excellent	55	Excellent
334	New York	Octover 21	Copenhagen	Good	34	Fair
335	Ohio	October 24	All seasons	Good	32	Good
336	Ohio	October 28	All seasons	Excellent	31	Good
337	Wisconsin	November 9	Holland	Poor	30	Poor
338	Wisconsin	November 9	All seasons	Good	30	Fair
339	New York	November 12	All seasons	Good	35	Poor
340	Wisconsin	November 25	All seasons	Excellent	..	....

EXPERIMENTAL

The analyses for sugar and nitrogen were made on the fresh material whereas the mineral elements were determined on the dried sample. Moisture was determined by drying at 100°C.; calcium, by the McCrudden (6, 7) method as used when iron is contained in the sample; phosphorus, by the volumetric method of the Association of Official Agricultural Chemists (8), and iron by the Walker (14) thiocyanate method. Precautions were taken to avoid bringing the material into contact with iron during the preparation and analysis of the samples.

The larger part of the cabbage was made into sauerkraut.   Details regarding the making of this kraut and the results obtained have already been published (10, 11) and will not be repeated here.

In table 1 are given the chief facts regarding the source, age, quality, etc. of the cabbage and sauerkraut.   Eighteen samples of 5 varieties of cabbage grown in 4 different states were obtained from kraut packers.   The first sample was taken on August 21, and on September 17 a second sample of this same variety from the same locality was obtained.   Samples were received

TABLE 2

Mineral and other nutrients of cabbage grown in various localities

NUMBER	CALCULATED ON BASIS OF FRESH VEGETABLES						SOIL	
	Mois-ture	Calcium	Phos-phorus	Iron	Nitro-gen	Total sugar as glucose	Type	Acidity
	per cent	per cent	per cent	per cent	per cent	per cent		
318	91.3	0.050	0.019	0.00037	0.15	3.49	....	....
322	92.9	0.049	0.018	0.00028	0.15	3.47	Fine sandy loam	Medium
324	93.6	0.042	0.019	0.00020	0.22	2.91	....	....
325	92.0	0.054	0.021	0.00031	0.23	4.20	....	....
326	92.3	0.047	0.032	0.00059	0.19	3.20	....	....
328	93.2	0.050	0.025	0.00029	0.16	3.03	Well decomposed peat	Very slight
329	93.3	0.043	0.023	0.00039	0.19	4.00	Silt loam	Very slight
330	92.7	0.056	0.022	0.00037	0.15	3.20	Silt loam	Very slight
331	93.2	0.029	0.021	0.00031	0.16	3.95	Silt loam	Very slight
332	93.9	0.038	0.017	0.00018	0.17	3.62	Sandy loam	Slight
333	92.7	0.051	0.023	0.00031	0.20	3.31	....	.....
334	93.4	0.034	0.026	0.00017	0.18	3.34	Silt loam	Very slight
335	93.3	0.055	0.027	0.00026	0.22	3.11	Sandy loam	Very slight
336	91.8	0.050	0.026	0.00022	0.18	2.98	Silt loam	Medium
337	91.4	0.056	0.037	0.00025	0.21	3.63	....	....
338	91.0	0.055	0.031	0.00029	0.22	3.10	....	....
339	91.7	0.052	0.023	0.00032	0.24	3.01	Silt loam	Very slight
340	93.0	0.046	0.017	0.00033	0.24	3.16	....	....
Average...	92.6	0.043	0.024	0.00030	0.19	3.38	....	....

throughout October and up to the end of the kraut season, about December 1. Most of the samples were better than the ordinary run of cabbage, as many were selected especially for their kraut-making qualities.   In general there was a good correlation between the quality of the cabbage and the quality of the resultant kraut.   To obtain a good kraut generally requires a good quality of cabbage, but the converse does not necessarily follow.

The mineral, nitrogen and sugar content of cabbage

Samples of soil were obtained from the packers in most cases at the same time as the samples of cabbage.   The classification of these soils together

with their acidity as determined by the Truog test is given in table 2. None of the soils were strongly acid and only 2 showed medium acidity.

In table 2 are also given the data showing the composition of the 18 samples of cabbage. The percentage of calcium varies from 0.029 to 0.056—an increase in the larger figure over the smaller of almost 100 per cent. The phosphorus content of no. 337 is more than double that of no. 332. The figures for iron show even greater variations: 2 samples are below 0.00018 and 3 are above 0.00036.

TABLE 3

The mineral and nitrogen content of sauerkraut

NUMBER	CALCULATED ON BASIS OF RAW KRAUT				
	Moisture	Calcium	Phosphorus	Iron	Nitrogen
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
318	91.2	0.052	.....	0.00049	....
324	92.9	0.043	0.016	....	0.22
325	91.2	0.052	0.021	0.00039	0.22
326	90.5	0.044	0.034	0.00046	0.20
328	91.8	0.064	0.033	....	0.18
329	92.0	0.054	0.023	0.00043	0.20
330	91.9	0.052	0.023	0.00050	....
331	89.9	0.049	0.027	0.00028	....
332	91.4	0.050	0.030	0.00036	0.15
333	89.9	0.066	0.030	0.00048	....
334	91.1	0.042	0.028	0.00036	0.17
335	91.5	0.061	0.028	0.00060	0.21
336	90.7	0.055	0.025	0.00072	0.16
338	91.0	0.054	0.027	0.00059	0.21
Kraut juice:					
Vat I*....................		0.055	0.023	0.00041	....
Vat II*..................		0.054	0.025	0.00040	....
Vat III*.................		0.053	0.025	0.00063	....
Average.....	91.2	0.052	0.026	0.00047	0.19

* Factory samples.

Great variations appear in the figures for nitrogen and sugar, but not so extensive as in the case of the three mineral elements. A notable feature about these figures is that they exhibit a seasonal change. The percentage of nitrogen increases while the sugar decreases as the season advances. No such seasonal variation is apparent in the figures for the mineral elements. If individual samples are compared with the average, it is also found that nitrogen and sugar vary inversely to each other. In any given sample if the percentage of nitrogen is below the average, the percentage of sugar is usually above the average.

Calcium and iron vary together in most of the samples, but there seems to be no particular relationship between calcium and phosphorus. In some

samples they increase together although in an almost equal number they do not. If the inorganic phosphorus had been determined, it is possible that some direct relationship would have been disclosed.

The mineral content of sauerkraut

The sauerkraut produced from the cabbage analyzed and reported in table 2 was removed from the container, dried, and analyzed. A considerable quantity of juice remains in the vat when the kraut is taken out. This juice is usually discarded. Such a practice is unfortunate, as it wastes a food product of essentially the same composition as the sauerkraut. The data for the kraut and kraut juice are given in table 3.

Because of evaporation and removal of water by escaping gases the moisture content of the kraut is from 1 to 2 per cent less than that of the cabbage.

TABLE 4

Loss of nutrients in making sauerkraut

MATERIAL OR ELEMENT CONSIDERED	NO. 335		NO. 336		NO. 338	
	Weight	Loss	Weight	Loss	Weight	Loss
	gm.	per cent	gm.	per cent	gm.	per cent
Raw cabbage................................	2000	....	7000	....	6000	....
Raw kraut..................................	1650	17.5	5820	16.9	5490	8.5
Dry matter in cabbage.....................	134	....	574	....	540	....
Dry matter in kraut........................	118	11.9	493	14.1	453	16.1
Nitrogen in cabbage........................	4.40	....	12.60	....	13.20	....
Nitrogen in kraut...........................	3.47	21.1	9.14	26.1	11.53	12.6
Calcium in cabbage.........................	1.10	....	3.50	....	3.31	....
Calcium in kraut...........................	1.01	8.2	3.21	8.6	2.96	10.3
Phosphorus in cabbage.....................	0.54	....	1.83	....	1.86	....
Phosphorus in kraut........................	0.462	14.4	1.46	19.8	1.48	20.4

The destruction of the sugars and the consequent production of carbon dioxide, ethyl alcohol, acetic acid, and lactic acid result in a decrease in the total weight of material. The minerals are not lost during the fermentation and must be either in the kraut or in the kraut juice. However, the percentage composition of the kraut is different from that of the cabbage because of the decrease in weight. The percentage of the mineral elements in the kraut is therefore somewhat higher than in the original cabbage. No particular change occurred in the nitrogen content of the kraut as compared with that of the cabbage.

Loss of nutrients in making sauerkraut

The weight of kraut was determined in three cases and the loss of the various nutrients was calculated from the data given in tables 2 and 3. The results, in table 4, show losses of from 10 to 20 per cent for the different con-

stituents. Of the mineral elements calcium showed the least loss, 9 per cent, and phosphorus the greatest, 18 per cent. The loss in weight of the cabbage as it fermented was about 14 per cent. In a number of experiments conducted by Huber (5), figures ranging from 8.8 to 17.4 per cent were found. The loss of nutrients would be materially reduced if the juice could be utilized as well as the kraut itself.

SUMMARY

Eighteen samples of cabbage from New York, Ohio, Illinois and Wisconsin were analyzed for calcium, phosphorus, iron, sugar, and nitrogen. The range for these constituents was as follows: calcium 0.029 to 0.056, phosphorus 0.017 to 0.037, iron 0.00017 to 0.00059, sugar 2.91 to 4.20, and nitrogen 0.15 to 0.24 per cent. Samples which were high in calcium were also high in iron. No relationship could be found between the variation of these elements and phosphorus. The early samples contained more sugar and less nitrogen than the late samples.

Sauerkraut made from this cabbage showed equally great variations in composition. The kraut juice was found to contain approximately the same percentage of food constituents as the kraut itself.

The loss of minerals and food constituents in making sauerkraut ranged from 10 to 20 per cent.

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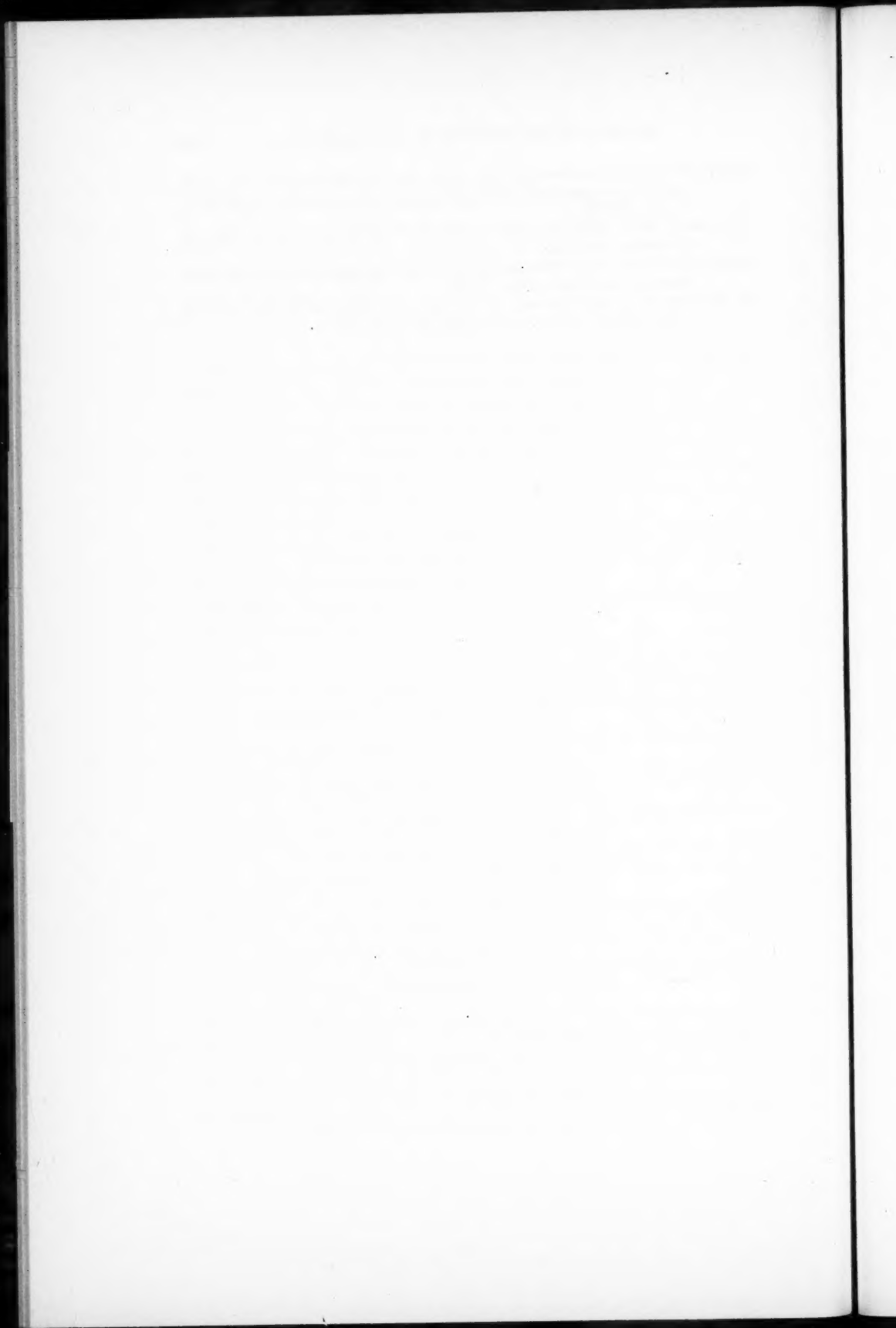
EFFECT OF THE CONCENTRATION OF POTASSIUM SALTS IN SOIL MEDIA UPON THE CARBOHYDRATE METABOLISM OF PLANTS. THE DIASTATIC ACTIVITY OF THE NASTURTIUM[1]

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The fact that potassium fertilizers exert a marked influence on carbohydrate metabolism seems to have been pointed out first by Nobbe (7) who found that a deficiency of potash caused a striking loss in the ability of the plant to manufacture starch.   This observation was later confirmed by Reed (8).   Studies at Rothamsted Experiment Station (9) have shown that mangolds, sugar beets, potatoes, and other sugar and starch forming plants reduced their production of carbohydrates with decreasing potassium supply even before the leaf area was diminished.   Stoklasa (12) believes that potassium is directly connected with the photosynthetic process and that formaldehyde is formed by reduction of potassium bicarbonate.   Loew (5) regards potassium as a condensing agent and showed that in certain instances it is able to effect changes which sodium can not.   In a study of the effect of commercial fertilizers on carnations Beal and Muncie (1) observed that the sap from the stems and leaves which had been fed large quantities of potassium sulfate contained a larger quantity of sugar than those receiving lesser amounts, whereas the starch content was lower.   From this data it seemed probable that the potassium salt might have increased both the rate of hydrolysis of the starch and the translocation of the sugars by activation of the diastatic enzymes of the plant.   Sherman and Thomas (10) have demonstrated that potassium sulfate and certain other inorganic salts and acids do stimulate to marked degrees the activity of malt amylase.   With these facts in mind it seemed advisable to make, insofar as possible, a study of the effect of the potassium fertilizers upon the diastatic activity of a plant.

EXPERIMENTAL

Production of the plant material

The nasturtium plant was chosen because of its ease of handling, its large leaf surface, and its high diastatic content.   Three 4-gallon stone jars of each of three kinds of culture media—yellow gray silt loam soil, white quartz sand,

and peat—were used at the start. These were planted February 15 to dwarf mixed nasturtium, about twenty seeds in each pot. The soils were watered with collected rain water, and no plant-food was added until after 2 weeks had elapsed from the planting date. The plants made their appearance on the ninth day.

For some unknown reason the stand secured on the sand, and particularly on the silt loam soil, was poor, and more seeds were planted in the vacant spaces. These, however, did not make any appreciable growth.

Potassium chloride was used as the source of potassium. This was made up at a concentration of 200 gm. to 2000 cc. of solution, and the applications were as follows:

Concentration	Amount of each application			
Low	2 cc. solution = 0.2 gm. KCl =	24.5 pounds per A.
Medium	10 cc. solution = 1.0 gm. KCl =	122.5 pounds per A.
High	50 cc. solution = 5.0 gm. KCl =	612.6 pounds per A.

Of the low amounts only two applications were made to the sand, and none at all to the soil or to the peat, the natural potassium content of these materials being sufficient.

As a nutrient solution for the sand cultures the following materials were used: $Ca(NO_3)_2 \cdot 4H_2O$, 80 gm. to 2000 cc. solution; NaH_2PO_4, 25 gm. to 1000 cc.; $MgSO_4$, 20 gm. to 1000 cc.; and $FeCl_3$, 0.2 gm. to 250 cc. They were applied as follows:

	Amount of each application		
Nitrate	24 cc. solution = 0.96	gm. $Ca(NO_3)_2 \cdot 4H_2O$ or 117 pounds per A.
Phosphate	12 cc. solution = 0.30	gm. NaH_2PO_4 or 36 pounds per A.
Sulfate	12 cc. solution = 0.24	gm. $MgSO_4$ or 29 pounds per A.
Chloride about	2 cc. solution = 0.0016 gm. $FeCl_3$	or 0.2 pounds per A.

The above solutions, including the KCl were applied at the end of the second week after planting, 10 days later, and thereafter every week or 10 days until a total of 8 applications had been made. However, toward the latter period of growth the high KCl applications were reduced about half because of the toxic effect upon the plants.

Observations during growth

The best growth as judged by size, vigor, and size and color of leaves was made on the peat; whereas the poorest was on the silt loam soil. The latter series was finally abandoned as worthless.

There was no noticeable difference in color, in size of leaf, or in strength of stems due to the variations in the potassium treatments. The potassium had less effect on the plants grown on the peat than on those on the sand, but in both cases the high concentration had a marked detrimental effect.

Harvesting

Using the appearance of the first bloom as a criterion for the stage in the growth of the plant when the diastase content is at its maximum, the plants were cut, measured and weighed on the morning of May 12 between 6:30 and 7:30. With some modifications, the process of curing recommended by Shuey (11) was followed. The plants from each pot were placed in a separate cheesecloth sack and hung in the attic to dry. After 2 days an electric fan was adjusted to blow a light current of air against the sacks for 3 more days. They were then placed in an electric oven and held at a temperature of 45 to 50°C. for 5 days. Shuey was able to dry alfalfa in 3 days at room temperature and in 2 days in the oven, but the nasturtium plant requires a longer period.

The material was then weighed, ground fine in a hand coffee mill, and placed in 4-ounce jars with screw caps in which it was kept until the chemical experiments could be made. The weights and measurements of the harvested plants are shown in table 1.

TABLE 1

Weights and measurements of harvested plants

	SAND			PEAT		
	Low K	Medium K	High K	Low K	Medium K	High K
Number of plants............................	14.0	15.0	6.0	18.0	16.0	22.0
Total green weight, gm......................	220.0	230.0	60.0	263.0	321.0	277.0
Green weight per plant, gm..................	15.7	15.3	10.0	14.6	20.0	12.6
Total dry weight, gm........................	44.5	34.0	7.5	36.5	48.5	48.5
Dry weight per plant, gm....................	3.2	2.3	1.2	2.0	3.0	2.2
Range in height, inches......................	6–22	6–23	6–10	6–20	7–21	5–18
Average height, inches.......................	12.7	14	8	11	15.6	10.1

In the case of the sand the dry weight yield decreased, both total and amount per plant, with the increase in potassium, whereas in the case of the peat the relation tends to be the opposite. The influence upon height of plant is very marked also but is of less consequence.

Determination of diastatic activity

The method of preparation of the extract used by Shuey (11) in his study of alfalfa was not applicable to the nasturtium material, for the extract was viscous and slimy and would not filter. Duggar's (4) procedure of digestion with 20 per cent alcohol also failed and recourse was had to the original method of Brown and Morris (2) which was modified as indicated below.

Procedure

In a small Erlenmeyer flask 0.5 gm. of finely pulverized air-dry plant material was placed, and 50 cc. of a 2 per cent starch solution added from a pipette, then a few drops of toluene. The solution was kept at 30°C. for 24 hours. For a blank, the solution was made up in the same way but was boiled for a minute immediately after adding the starch. At the end of the incubation period reducing sugars were determined by Defren's (3) method on 10-cc. portions of the infusion. If the flask of starch and plant material was not disturbed for two or three hours previous to the determination, the solid matter settled sufficiently to permit the pouring off of the supernatant liquid. The reduced

TABLE 2

Diastase activity in nasturtium plants grown in sand and in peat in the greenhouse with varying amounts of K in the soil

Digested 24 hours

| | DEXTROSE | | | | | ACTIVITY |
	Blank	Blank	(a)	(b)	Gain	
Sand						
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Low K..............................	10.90	12.00	37.45	37.20	25.87	0.258
Medium K...........................	8.86	9.60	27.85	28.40	18.89	0.188
High K.............................	6.81	6.81	16.60	16.80	9.89	0.098
Peat						
Low K..............................	15.85	16.80	28.60	28.94	12.45	0.124
Medium K...........................	9.79	.....	29.80	29.80	20.01	0.200
High K.............................	7.54	7.54	24.00	23.50	16.21	0.162

copper was estimated by the method of Low (6), and the glucose calculated from Defren's table. The activity equals the difference in grams of glucose between the blank and the sample, divided by the weight of plant material represented by the 10-cc. aliquot. The results are given in table 2.

These results are somewhat contrary to what had been expected. The activity in the material grown in sand decreases with the increase in potassium whereas that in the material grown in peat tends to have the opposite effect, though the relation is not so definite. Apparently in the case of the sand cultures, the potassium concentration of the low amount was too great. Perhaps all three concentrations should have been less. That there was an abundance of potassium in all cases was evidenced by the fact that in the growing plant there was no indication whatever of potassium deficiency.

In the peat which was originally low in potassium, the addition of that element was beneficial to a certain point and then was somewhat detrimental.

The toxic action of the potassium salt in the peat was much less severe than in the sand. This is to be expected, for the colloidal nature of the peat would tend to cause an absorption of the potassium ions much more readily and thus would reduce the toxic effect.

It will be noted that the variations in the diastatic activity agree fairly well with the variations in dry weight as given in table 1, and in general correspond to the vigor as observed in the growing plant. It is possible to assume that the diastatic activity is more dependent upon favorable conditions for plant growth than upon the presence or absence of any one element; that is, unfavorable growing conditions whether due to a deficiency or a harmful excess of one or more elements, or to a deficiency or an excess of soil water, might cause an approximately equal retardation in diastase content.

SUMMARY

Nasturtium plants were grown in the greenhouse in pots of sand and of peat, treated with different amounts of potassium for the purpose of determining the effect of the potassium upon the amount of diastase in the leaves and stems.

The activity decreased with the increase in potassium, in the case of the sand; whereas in the case of the peat cultures, the medium application of potassium gave the highest activity, and the lower application the least activity. This is in direct relation to the yield in practically every case.

The results obtained suggest a correlation of diastase activity with favorable growing conditions in general rather than with the presence or absence of any one or more elements.

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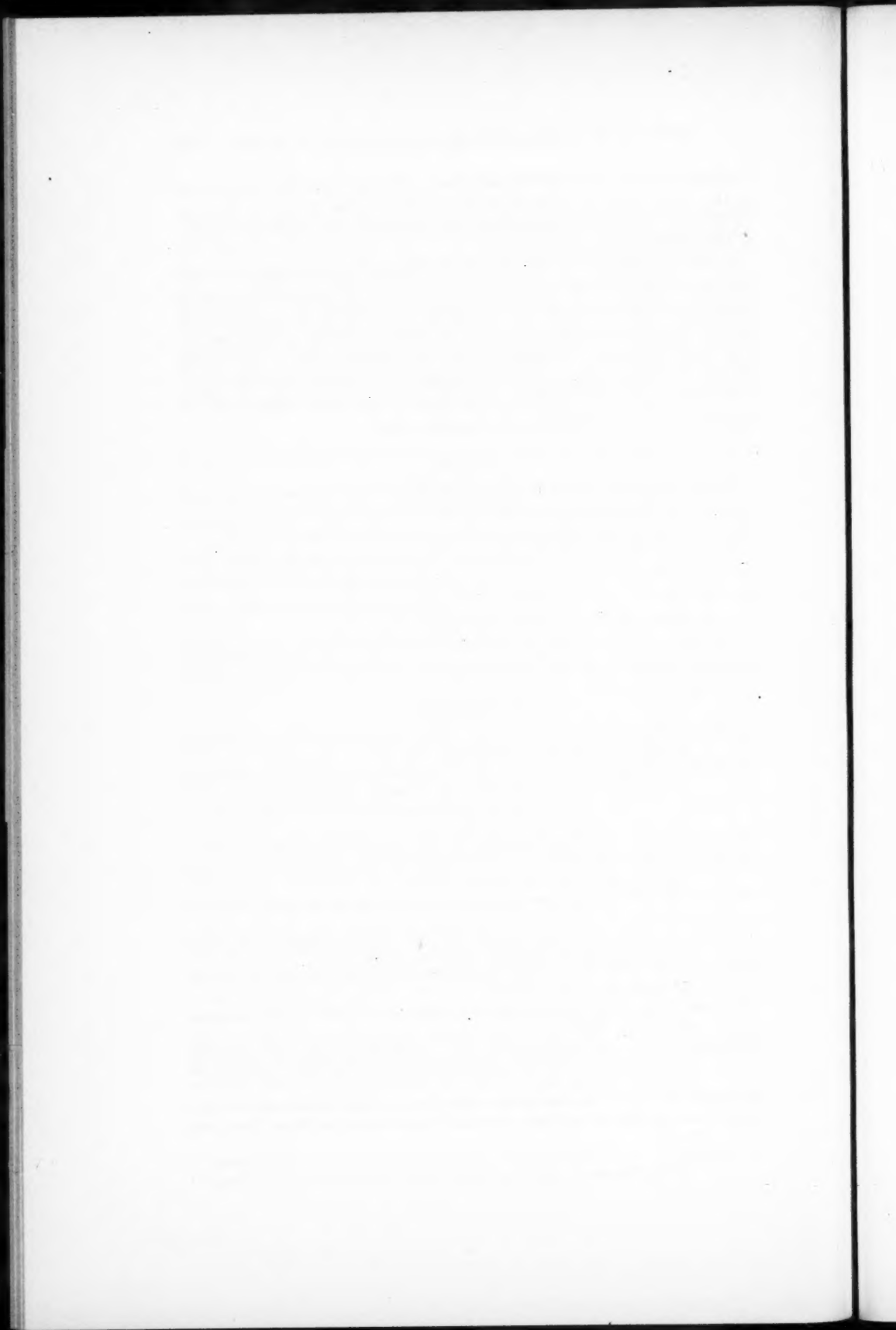
A MOVABLE LYSIMETER FOR SOIL STUDIES

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In only a few cases have lysimeter studies been made on large sections of soil in an undisturbed condition. Where this has been done the soil columns have usually been surrounded by some sort of masonry. As it has been found very difficult to make such masonry absolutely water-tight, there has been trouble from leakage, which has destroyed the accuracy of the work. In 1916 some lysimeters were constructed of concrete at the Missouri Station, but it was not found possible to waterproof these satisfactorily.

On account of this difficulty in making concrete or masonry waterproof, a new type of container has been devised, which it is believed has certain important advantages over lysimeters now in use.

DESCRIPTION OF CONTAINERS

The new lysimeter, a diagram of which is shown in figure 1, consists of a heavy galvanized iron open cylinder (16-gauge iron) built with a removable bottom which is provided with a drainage hole. The cylinder is $1\frac{1}{2}$ inches greater in diameter than the core of soil desired. The bottom is provided with 8 clamps through which $\frac{1}{4}$-inch bolts are inserted so that it can be drawn up tightly against the bottom of the soil column when put in place. The drainage hole was covered with a perforated copper plate and over this were placed two thicknesses of copper gauze. Over this was spread enough lead shot to completely fill the depression made by the sloping bottom. A layer of large lead shot (BB) was placed in the bottom and then a few layers of no. 6 shot were placed over this so that when the bottom was put into place these came up against the soil. This arrangement affords adequate drainage.

SOIL CONDITIONS

The soil should be rather dry when put into lysimeters of this type. If put in when in a moist condition, the soil will shrink upon drying and draw away from the sides of the container, thus allowing the water during the next rainfall to run down the walls and into the drainage tube without actually passing through the soil. The internal pore space and the open upper end of the cylinder will allow for expansion of the colloidal material upon wetting. Moisture determinations were made upon 1-foot sections of several samples taken with a King sampling tube a few inches from the edge of the cores.

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The volume weight of soil was also determined so that the total weight of the water in the lysimeter could be calculated.

In order to prevent excessive drying by the sun and wind or wetting in case of rain, a large tent was stretched over the place where the soil columns were being removed. The work was done in November when the rate of evaporation was so low that the cores lost very little water during the short time they were exposed.
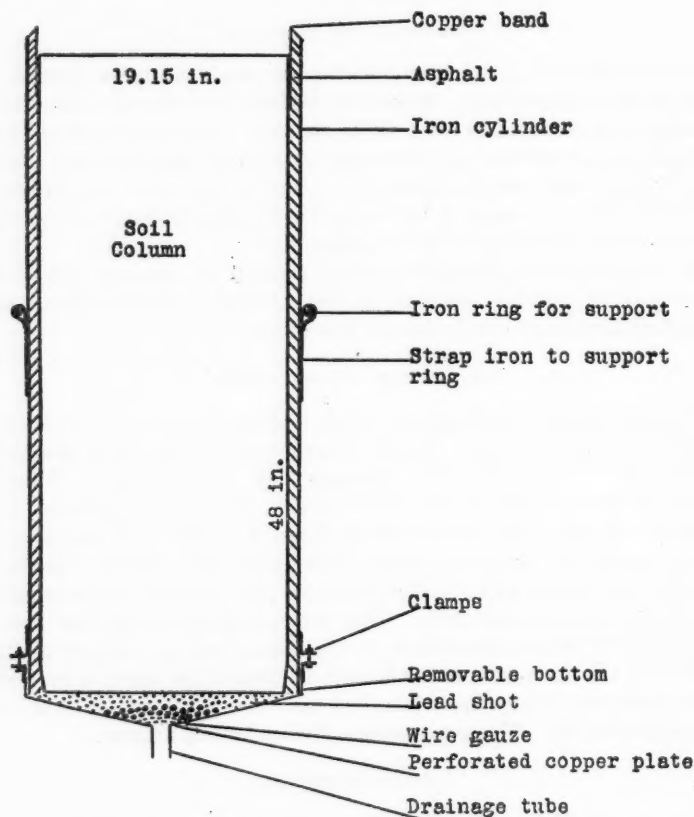
FIG. 1. DIAGRAM SHOWING ESSENTIAL PARTS OF MOVABLE LYSIMETER

CUTTING THE SOIL COLUMNS

It was necessary to dig a trench about eighteen inches wide and five feet deep around the location for the two soil columns which were about two feet apart. About six inches of soil was left entirely around each core until the trench was completed. This layer was carefully shaved off until the core was

of the exact size desired and all the sides were plumb. A copper band 9 inches wide and of the exact diameter desired (19.15 inches—enclosing 2 square feet of surface) was carefully drawn down until it projected only 3 inches above the surface of the ground. The soil column was made 4 feet high and a shoulder of soil was left, upon which the iron cylinder could rest.

ENCASING THE SOIL COLUMN

After the core of soil had been trimmed to the proper size and carefully smoothed the open iron cylinder was placed over it. By careful adjustment the same space was allowed on all sides between the cylinder and the soil column. The lower end was fitted on the shoulder of soil mentioned above, and any openings around the bottom were carefully stopped with clay.

The space between the cylinder and soil column was then filled with a high grade asphalt or battery sealing compound obtained from the Standard Oil Company. This material has a melting point of 175° to 180°F. It has excellent adhesive qualities and will remain at much the same consistency from 32° to 100°F. About two gallons of this melted material was placed in a bucket and weighed. The temperature was then reduced to 160°C. when it was slowly poured around the core inside the iron cylinder. About five minutes was consumed in pouring in one bucketful of material and then about thirty minutes was allowed for cooling before the next bucketful was added. This precaution was thought necessary in order to prevent too great heating of the soil. After the space was filled to within 3 inches of the top the asphalt was allowed to cool thoroughly, after which the remaining space was filled with asphalt.

ATTACHING BOTTOMS

After the asphalt had hardened, a hoist was attached to the iron ring near the middle of the cylinder. A Ford truck equipped with a wrecking crane was used for this purpose. The chains were tightened until they were under considerable tension, after which the soil column was cut off even with the bottom of the cylinder. The cohesion between the asphalt and the soil was depended upon to hold the column in place. When the column was completely severed from the material below, the lower end of the column was carefully dressed until even with the edge of the cylinder. The removable bottom containing the lead shot and provision for drainage was then put on and firmly bolted into place. All joints around the bottom were carefully sealed with asphalt and the lysimeter was ready to be transported to the permanent pits.

TRANSPORTING

The lysimeters were hoisted out of the pit by means of the crane and hauled about twenty rods to a permanent concrete pit provided for them. Heavy iron frames with adjustable hooks support the cylinders in place. (See plate 2, fig 1.)

WEIGHING

Weights were taken of the iron cylinders and all asphalt, shot, or other material used.   When the lysimeters were placed in the pits they were weighed on a 1250-pound steelyard.   The total weight of each lysimeter was approximately 1120 pounds.

After the lysimeters were properly in place a sheet of galvanized iron was cut to fit over them, and collars were fitted around the tops and sealed with asphalt to prevent water running down the sides of the cylinders into the concrete pit.   Receptacles of 12-liter capacity were placed under the drainage holes and proper connections made by means of rubber tubes.

ADVANTAGES OF THIS MOVABLE TYPE OF LYSIMETER

1. The lysimeters herein described provide for studying the drainage and evaporation from soil in an undisturbed condition.

2. It is believed that these lysimeters have several distinct advantages over stationary lysimeters even where the soil is left in place.   They undoubtedly have a much greater advantage over stationary or other movable lysimeters where the soil has been removed from its original position and placed in the containers.

3. The lysimeter used in this work can be made absolutely water-tight and all chance for leakage into or out of the walls of the container can be entirely eliminated.

4. The cylinder can be inspected at any time and any case of injury can be readily detected and easily repaired.

5. The lysimeter can be weighed and the amount of water held or that lost by evaporation throughout any given period can be easily and accurately determined.

6. Soils of different types or even from widely separated areas may be placed in cylinders and transported in an undisturbed condition to a central location for study.

7. Lysimeters of different depths or of different diameters may be compared in the same pit.

8. Although the temperature of the soil in these cores will probably fluctuate more than would be the case with lysimeters encased in concrete and buried in the ground, much of this variation can be eliminated by the proper construction of the containing pit.

PLATE 1

FIG. 1. Excavation showing how soil columns were obtained.   One has the cylinder on and part of the asphalt has been put in.   The other core is ready to be dressed.

FIG. 2. Method of transporting lysimeters.
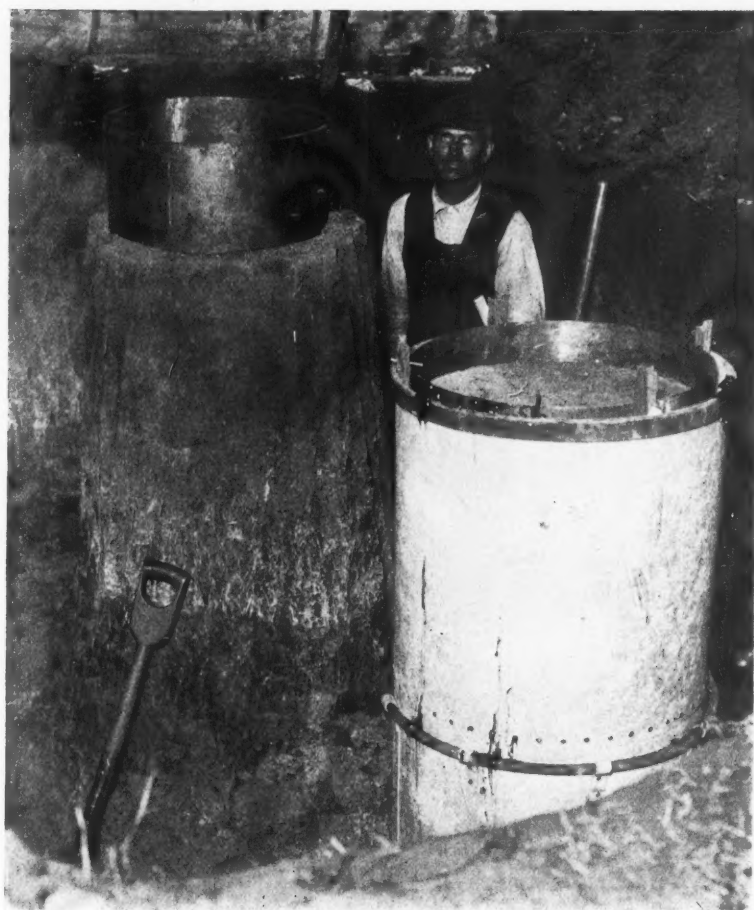
Fig. 1

Fig. 2

PLATE 2

Fig. 1. Lowering lysimeter into permanent pits. Heavy iron frames with rods for supporting lysimeters are shown resting on the concrete walls.

Fig. 2. Lysimeters in place with pit covered and collars attached.

Fig. 1

Fig. 2

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THE RELATIONSHIP BETWEEN SOLUBLE IRON AND COLLOIDS IN CERTAIN RESIDUAL CLAYS

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The experiments described in this paper are part of an extensive series on the coloration of soils and sediments, but are of sufficient interest in themselves to deserve separate discussion.

Six different clays and clayey materials were experimented with:

1. A plastic, red, clayey subsoil derived from the decomposition of a coarse-grained granite at Chapel Hill, N. C. 2. A plastic yellow clay, which is the decomposition product of fine-grained aplitic dikes cutting the aforementioned granite and which was obtained from the same pit as was no. 1. 3. A deep brick-red clay weathered from the red Triassic sandstones of the same region. 4. A commercial kaolin from a decomposed pegmatite at Spruce Pine, N. C. 5. A yellowish brown residual soil from a New Jersey diabase. 6. A hard, red roofing slate of unknown origin.

The percentage of "colloidal" material contained in these six samples was obtained by a modification of the methods described by Gile et al. (1). The modified method differed in that no centrifuge was used, the suspension being allowed to settle under the influence of gravity alone. The clays were rubbed up under water, a few drops of ammonia were added, and the resulting suspension was allowed to stand in a tall glass jar for 48 hours. At the end of this time the liquid was siphoned off, care being taken not to disturb the material which had settled out, and the suspensoids were separated from the liquid by passing it through a Berkefeld bacteriological filter. The sludge resulting from this operation was then concentrated and dried at a low temperature, which was never allowed to exceed 110°C. This material appeared to be a typical colloid inasmuch as it exhibited great shrinkage, slaked rapidly; showed an increase in volume when moistened, and, in the dry condition, adhered strongly to the tongue. No preliminary treatment was given, except in the case of the slate, which, as it had not been disintegrated by soaking for several days in water, was ground to 80 mesh.

One- to two-gm. samples of the clays and of the corresponding colloid fractions were then ground to 100 mesh and placed in a vacuum desiccator over a 3 per cent solution of sulfuric acid for 5 days. During this time the air was kept exhausted by an aspirator. At the end of 5 days the samples were removed, weighed, heated for 15 hours at a temperature of 115°C., and weighed again,

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the loss representing the amount of water vapor adsorbed.   In order to obtain
the percentage of colloids the formula (1, p. 7).

$$\frac{\text{adsorption per gram of clay}}{\text{adsorption per gram of colloid}} \times 100$$

was applied, and the percentage of colloidal material contained in each of the
six samples was obtained (table 1).

In order to obtain the amount of soluble iron present each sample was then
treated with dilute hydrochloric acid until its color was discharged or until
it was obvious that no further change in color could be expected; the solution
was reduced by sulfuric acid and zinc; and the iron was determined by titra-
tion with potassium permanganate.   The color was removed completely from
samples 1, 2, 3, and 4, and incompletely from samples 5 and 6.

It was believed that the color of greatly weathered soils and subsoils was due
to the presence of one or more hydrous iron oxides in a colloidal condition, and

TABLE 1

Percentage of colloidal material as obtained by adsorption method

	NUMBER 1	NUMBER 2	NUMBER 3	NUMBER 4	NUMBER 5	NUMBER 6
Colloidal material, *per cent*.......	41	68	29	50	48	25

TABLE 2

Percentage of colloidal material as obtained by iron ratios

	NUMBER 1	NUMBER 2	NUMBER 3	NUMBER 4	NUMBER 5	NUMBER 6
Colloidal material, *per cent*........	45	78	32	58	71	48

an attempt to prove or disprove this belief was made.   If the soluble iron were
all colloidal it should appear in the colloid fraction in the same ratio as the other
colloids.   This assumption could be tested, therefore, by substituting "iron
content—soluble" for "adsorption" in the formula quoted above.   This was
done, with the results shown in table 2.

It will be seen that in the case of samples 1, 2, 3, and 4, which are greatly
weathered, the percentage of colloids as obtained by the iron method is but
little greater than that obtained by the adsorption of water vapor, being
roughly about one and one-tenth times more.   Samples 5 and 6, on the con-
trary, contained large amounts of undecomposed mineral grains and there-
fore much iron not in a colloidal condition.   It is only to be expected then,
that the two results for these samples should be very discordant.

Since these experiments would seem to show that the soluble iron in a com-
pletely weathered clay or soil is in the colloidal condition, whereas in less com-

pletely weathered material there are larger amounts of non-colloidal iron, it would seem that here we may have a method of estimating the degree of weathering without resorting to a mineralogical examination of the material. Further experiments along these lines are being carried on by the author. Results so far obtained suggest that the deviation of the colloid percentages as obtained by the iron ratios from one and one-tenth times the percentages as obtained by water adsorption, gives a rough approximation of the reciprocal of the weathering factor; that is, the greater the deviation, the less the weathering.

Conversely, if it is certain that the materials under consideration have been completely weathered, the method of iron ratios would seem to give as accurate results as the method of water adsorption for the determination of the percentage of colloidal material present, and at a great saving of time, for the 5 days in the desiccator is replaced by an iron analysis occupying but a few hours.

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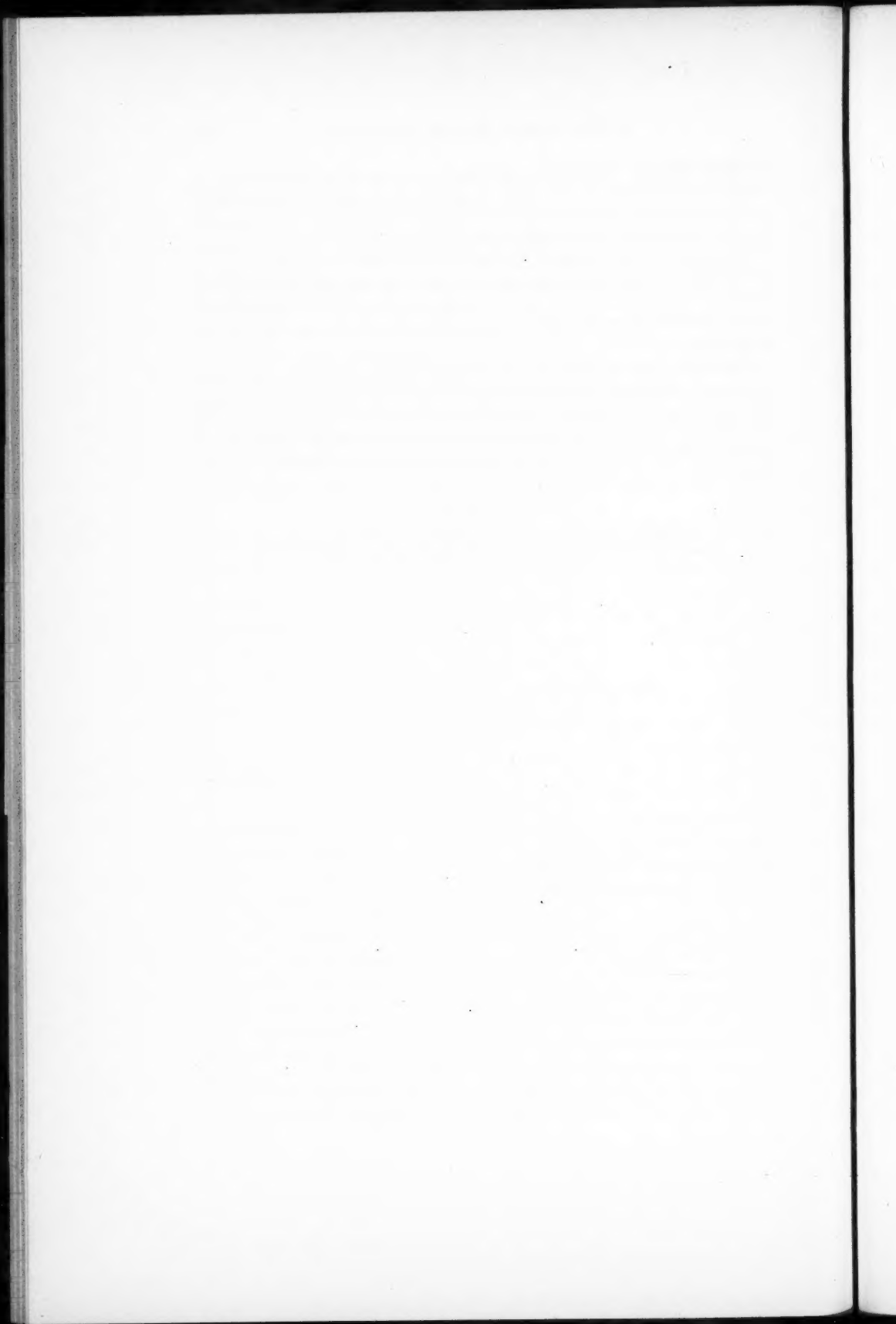
BASE EXCHANGE IN RELATION TO ALKALI SOILS[1]

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The base-exchange property of soils has been studied by a large number of investigators in many different countries, and numerous soils representing a wide range of types and conditions have been used. The results have been singularly consistent. Everywhere it has been found that the soil possesses the property of base exchange. The principle seems to be one of universal application. The fact is also well established that such salts as occur here and there in arid regions are capable of reacting with soils by base exchange. When a solution of these salts is brought into contact with the soil the reaction takes place rapidly; if the two are shaken together vigorously, approximate equilibrium is attained within a few minutes.

A part of the base of the salt displaces an equivalent amount of the soil bases. The former passes out of solution and becomes a component of the soil complex; the latter pass into the solution and may then be leached away, provided, of course, that insoluble compounds are not formed. When chlorides and nitrates are used the salts formed by base exchange are of high solubility, but, as was pointed out by Gans (6) in 1905 and more recently by others, the use of solutions of carbonates and phosphates leads to the formation of insoluble precipitates.

During recent years it has been shown that a given soil always contains a fairly definite amount of total exchangeable base, but different soils may contain rather widely different amounts. The reactive constituents reside chiefly in the clay fraction, whereas the coarser materials play a minor and usually a relatively unimportant part. The clay materials of different soils, however, seem to vary considerably in their base-exchange capacity. The lighter soil types, because of their small content of clay, apparently always have a relatively low base-exchange capacity. With normal soils the chief replaceable bases present are Ca and Mg, with Ca usually, though not always, greatly predominating.

The exchange reaction is subject to the principles of mass action and chemical equilibrium. When a dilute solution of NaCl, for example, is shaken with a soil, the exchange of bases proceeds to a limited extent only. With a more

concentrated solution, the reaction goes still farther; but under equilibrium conditions the exchange never becomes complete, no matter what concentration of NaCl is used. The principle of chemical equilibrium prevents complete exchange. However, when the equilibrium is continually disturbed by removing the soluble products of the reaction, as is the case when the soil is thoroughly leached with a solution of NaCl, or when the solution contains compounds with which the displaced bases may form insoluble precipitates, the reaction may finally go to completion, or at least approximately so. In this case the soil will contain Na as its only replaceable base.

An extended review of the voluminous literature on this subject seems unnecessary at this time. Various workers have made use of the base-exchange principle in the investigation of alkali soils. The work of Gedroiz (7, 8, 9, 10, 12) in Russia is outstanding in this connection. De'Sigmond (3) has found it useful in the study of Hungarian alkali soils, as also have Dominicis (4) in Italy, Prescott (20) in Egypt, Scofield and Headley (21) in the United States Department of Agriculture, and our laboratories in California (1, 17, 18).

In a previous communication (1) we have shown, in common with various others (4, 7, 20), that the base-exchange reaction affords an effective means for the formation of Na_2CO_3. When a high concentration of Na salt, such as NaCl or Na_2SO_4, comes into contact with the soil, an exchange of bases takes place, as indicated above. Upon leaching out the soluble products of the reaction, the exchangeable Na compounds that have been formed undergo partial hydrolysis and decomposition with the resulting formation of NaOH, which then becomes converted into the carbonate or bicarbonate by the CO_2 present.

In addition to the more direct relation between base exchange and the formation of Na_2CO_3, Cummins[2] has also found that the soil, through its intermediate base-exchange reaction, affords the needed mechanism for the continuation of the well-known Bertholet reaction whereby Na_2CO_3 is formed. The soil in this case may serve to absorb the soluble Ca salts that are formed and thus promote the formation and accumulation of relatively large amounts of Na_2CO_3.

Soils that are relatively high in replaceable Na apparently always yield alkaline aqueous extracts. Upon reducing the concentration of the neutral Na salts that are present in alkali soils by leaching, the alkalinity frequently increases, and quite markedly so in the presence of $CaCO_3$. Such soils continue to yield highly alkaline extracts for a long period. The base-exchange reaction is fundamentally responsible for this fact.

It has also been frequently observed that various Na salts produce injurious physical effects on soils. Gans (6) pointed out in 1905 that $NaNO_3$ promotes the deflocculation of soils and may lead to deleterious physical effects. His-

[2] Unpublished manuscript.

sink[3] (14) showed in 1907 that soils leached first with NaCl and then with water may become almost completely impermeable. Similar treatment with Ca salts increases the permeability. In 1909 Hall (13) called attention to the deflocculation that has resulted from the use of $NaNO_3$ at Rothamsted. Hissink (15) has discussed the injurious physical effects produced by sea water. Sharp (22), Scofield and Headley (21) and our laboratories (1, 16, 17) have made similar observations in America. In his studies on this subject Gedroiz (12) found that when a 20-gm. sample of Na-saturated heavy clay was shaken with 100 cc. of water and allowed to stand quiescent, the suspension showed practically no sedimentation after 7 months. The same clay when saturated with Ca settled out quickly.

In harmony with these observations is the well-known fact that the permeability of natural alkali soils frequently undergoes pronounced reduction on flooding the land. It is also well known that certain alkali soils may be reclaimed by relatively simple means, whereas others yield to treatment with difficulty. In certain cases mere drainage, with or without flooding, suffices to give good results. In other instances drainage and flooding are relatively ineffective. Investigations on the base-exchange phenomenon have been helpful in this connection. By the use of comparatively simple laboratory methods it is possible to determine at least the general nature of the reclamation methods that must be applied.

Since Na salts react with soils by base exchange, it would seem that many natural alkali soils must necessarily contain Na in exchangeable form. Gedroiz (8) has verified this fact with certain Russian soils. Prescott (20) made similar observations on soils from the valley of the Nile. In a recent paper (18) we have shown the same to be true with several American alkali soils. More recently we have investigated a considerable number of alkali soils taken from widely separated places and representing several of the more important alkali areas of America. The results have thrown some additional light on the subject.

DISCUSSION OF METHOD

An outline of the method employed in these investigations was given in a previous publication (18). The method consists essentially in leaching a sample of soil with normal NH_4Cl until its replaceable bases have been completely displaced by NH_4. The extract is then analyzed for bases. By making due allowance for the water-soluble bases the amounts exchanged may be calculated. Theoretically the solubility effects, in addition to the displacing effects of NH_4, must also be considered, for it is certain that the

[3] Our attention has been called to the fact that Dr. Hissink began his investigations on base exchange as early as 1906 (Chem. Weekbl., v. 3, p. 802). Subsequently he has published several important papers on this subject. Some of his earlier papers were unknown to us until recently. Consequently an injustice, we regret to say, was done Dr. Hissink in a previous reference to his paper (18).

various minerals present are soluble to some extent in NH_4Cl solution. Moreover, certain alkali soils apparently contain significant amounts of especially soluble silicates. Where these silicates are absent the solubility effect is of minor importance unless the soil contains $CaCO_3$ or $MgCO_3$. In this latter case a special correction based on a determination of the carbonate must be introduced.

When the soil contains an amount of $CaCO_3$ greatly in excess of its solubility in the NH_4Cl solution used, a highly accurate determination of replaceable Ca is rather difficult. This is due to the fact that Ca is a more active displacing base than the other soil bases or NH_4. Calcium carbonate being soluble to a considerable extent in NH_4Cl solution, the equilibrium principle operates to prevent the complete displacement of the replaceable Ca. In fact $CaCO_3$ may serve to effect the substitution of more or less Na when an alkali soil is merely leached with water. For this reason a limited amount of substitution of Na by Ca may take place in the usual determination of the water-soluble salts, but the magnitude of this substitution is probably not very great unless the soil is treated with a relatively large volume of water.

When an alkali soil which contains $CaCO_3$ is extracted with NH_4Cl solution the Ca concentration of the resulting solution may become high enough not only to prevent the displacement of the last traces of replaceable Ca, but also to cause a certain amount of $CaCO_3$ itself to serve as a displacing agent. If the soil is approximately saturated with Na at the outset, it may thus be caused to acquire a certain amount of replaceable Ca at the expense of $CaCO_3$. Gedroiz (10) has called attention to the necessity of continuing the extraction until the carbonate is all dissolved. Then by calculating the Ca equivalent of the CO_2 removed from the soil and subtracting this quantity from the total Ca dissolved, the difference will represent replaceable Ca. In a few instances we have found, however, that in addition to the displacement of bases the solubility of constituents other than carbonates may become considerable upon prolonged extraction with NH_4Cl solution.

With certain alkali soils the determination is further complicated by the fact that Mg carbonates may be present also. In fact we believe that $CaCO_3$, the double carbonate of Ca and Mg (dolomite), and basic carbonate of Mg are all present in certain alkali soils. Where these occur we know of no method for the accurate determination of replaceable Ca and Mg.

The determinations were made by digesting 25 gm. of soil for several hours with 250 cc. N NH_4Cl, transfering it to a filter, and leaching it to 1 liter with a solution of N NH_4Cl. The filtrate was then analyzed. The Ca equivalent of the CO_2 dissolved, (as ascertained by determining the total carbonate in the soil before and after the extraction), was first calculated and the result subtracted from the Ca determination. If the amount of Ca found was insufficient to combine with the CO_2 dissolved by NH_4Cl, the remainder was referred to Mg. If Ca and Mg carbonates are both present, this method tends to give low Ca and correspondingly high Mg figures; but, except where

soluble silicates occur, the sum of the chemical equivalents of the Ca and Mg as calculated by this method is probably reasonably accurate. The great majority of the soils studied do not contain any Mg carbonate. The determination of replaceable K and Na is not affected by the alkali earth carbonates.

As a check on the accuracy of the method, we have determined the NH_4 content of the soil after the soil was extracted with NH_4Cl and after the adhering and occluded NH_4Cl was removed. Since the substitution of soil bases by NH_4 is stoichiometric, the NH_4 determination should give a reasonably accurate measure of the exchange. As stated above, the exchange will not be entirely complete as long as there is any considerable amount of $CaCO_3$ in the soil. With certain samples we have continued the NH_4Cl extraction until practically all the carbonate was dissolved, and then NH_4 was determined in the residue. If the amount found did not exceed the sum of the K and Na as determined by the usual extraction with NH_4Cl, we have assumed that the original soil was approximately saturated with monovalent bases and, therefore, did not contain appreciable amounts of replaceable Ca or Mg. This proved to be the case with several black-alkali soils. Although this assumption may not be mathematically exact, we believe that it is reasonably sound.

If the soil contains excessive amounts of water-soluble Ca it may be necessary to leach with water thoroughly before making the determination of replaceable Ca, but the determination of replaceable K and Na should be made on the unleached sample. If a soil which contains a considerable amount of replaceable Na is leached with water, an alkaline extract is usually obtained; when $CaCO_3$ is present the substitution of its Ca for Na may lead to the loss of substantial amounts of replaceable Na. Leaching such a soil with ordinary distilled water, which usually contains more or less CO_2, undoubtedly further augments the loss of Na both through the direct substitution of H for Na and because of the solubility of $CaCO_3$ in carbonated water.

With the exceptions noted, we believe that it is possible to secure reasonably accurate results with the NH_4Cl method, but it is not well suited to routine work. With soils that contain carbonates this method requires considerable care. It is hoped that a better method may soon be proposed. The use of a dilute acid, as recommended by Gedroiz (11), suggests itself for this determination. It is possible, though not probable, that a strength of acid may be found which will decompose the carbonates and displace the bases without having any appreciable action on other constituents present.

In considering the quantitative aspects of this subject it is also important to bear in mind that most soils probably contain at least two general classes of base exchange compounds. One of these is extremely reactive, the other much less so. Numerous workers have noted that the rate of the base-exchange reaction in soils is rapid, and that the most reactive constituents reside in the clay fraction, the so-called colloidal material of soils. Lemberg (19), Sullivan (23), Cummins and Kelley (1) and others have shown, however,

that various crystalline silicates, common to soils, are also capable of undergoing more or less base exchange with salt solutions. The analytical results obtained on a given soil are probably influenced to some extent by both of these classes of substances. Since the more reactive components appear to be much the more important, the object is to determine these with as little interference by the less reactive substances as possible.

In his studies on artificial zeolites, Gans (6) pointed out that the method of preparation greatly influences the reactivity of the resulting substance. On the basis of the method of preparation, Gans hypothesized that a given base is readily exchangeable or not, depending upon its position in the molecule. By dissolving Al_2O_3 in an excess of NaOH and then heating with SiO_2, a very reactive product was obtained. If the SiO_2 was first dissolved in NaOH and then Al_2O_3 added, a much less reactive product was obtained. On the basis of this evidence Gans designated the reactive product as an aluminate silicate.

In view of the complexity of the systems involved in soils; the ready reactivity and lability of some of the constituents; the presence in alkali soils of relatively high concentrations of soluble salts, whose determination may affect the exchangeable constituents to some extent; and the errors due to solubility effects, it is not reasonable to expect highly accurate results with any method. Nevertheless, we believe that important general conclusions may be safely based on the data obtained.

EXPERIMENTAL RESULTS

The soils studied represent wide contrasts. They were taken from various localities in California, Arizona, Nevada, Utah, and Idaho. The data shown in tables 2, 3 and 4 are expressed as percentages of dry soil and also as percentages of the total replaceable bases calculated to an equivalent chemical basis. The latter bring out the more fundamental facts. As shown in table 1, the concentration and composition of the water-soluble salts varied greatly. Both the absolute and the relative amounts of the replaceable bases were also very variable.

It may be helpful to recall in this connection that with the exception of highly acid soils Ca comprises the principle part of the replaceable bases of most normal soils. The sum of the Ca and Mg usually equals more than 80 per cent and frequently as much as 90 per cent of the total replaceable bases. Non-alkali soils ordinarily contain very small amounts of replaceable Na.

It will be observed that the soils reported in table 2 contain very much more replaceable Na than any other base. Most of these soils also contain exceptional amounts of replaceable K, but none of them contains a high relative percentage of replaceable divalent base. The relationships of the several bases, therefore, are quite different from those of normal soils. The soils reported in table 3 occupy an intermediate position between those reported in table 2 and normal soils. Apart from the water-soluble salts, the dif-

ference lies primarily in the subnormal content of replaceable Ca and the correspondingly increased content of replaceable Na. On the other hand, those alkali soils reported in table 4 are essentially normal in so far as their replaceable bases are concerned.

Every soil reported in table 2, with the exception of the sample from Logan, Utah (7070), contained water-soluble carbonate. In addition, all of them contained a relatively high concentration of water-soluble Na, either at the

TABLE 1

Water-soluble salts in alkali soils

(Expressed as parts per million)

LABORA-TORY NUMBER	Ca	Mg	K	Na	CO$_3$	HCO$_3$	Cl	SO$_4$	NO$_3$
4585	18	22	320	2,209	405	457	2,256	698	435
5190	94	121	50	10,861	103	381	14,125	3,803	0
5696	29	24	132	4,902	255	412	4,906	2,664	635
6145	9	5	39	691	585	183	160	134	79
6376	33	63	260	8,000	255	656	7,859	4,990	95
6377	14	36	134	5,300	405	564	5,549	2,800	0
6539	52	48	135	1,835	435	1,004	435	2,145	0
6540	40	37	103	1,540	495	1,127	408	1,322	0
6541	24	24	115	1,012	450	793	284	754	0
6809	25	24	150	2,215	30	1,036	1,274	2,313	26
7070	53	56	252	4,061	0	640	3,787	3,495	0
7073	13	26	240	972	330	1,037	390	534	0
6139	8	20	42	804	390	793	151	175	67
6140	6	11	36	607	330	640	106	111	32
6138	13	17	38	404	165	747	35	83	10
6155	115	83	97	1,167	0	366	1,637	628	14
6297	10	22	24	491	0	168	638	31	9
6298	220	71	72	3,403	0	214	2,035	5,003	89
7074	25	42	420	1,394	120	1,250	656	1,606	0
887	610	230	188	2,744	0	214	2,350	695	5,000
6157	253	175	18	552	0	61	1,282	708	9
6158	2,175	488	32	1,280	0	229	443	9,073	0
6288	1,551	491	152	3,609	0	168	7,812	2,523	194
6372	2,830	3,211	504	14,082	0	168	31,904	4,830	165
6373	2,603	428	211	5,540	0	153	8,496	7,569	435
6374	3,498	800	262	5,916	0	168	10,195	9,868	510
6375	880	340	128	2,630	0	290	3,009	4,635	200
6522	2,772	1,617	2,000	15,105	0	305	18,160	22,245	0

time when the samples were drawn or else previously. They are characterized by a low concentration of soluble Ca and Mg. The relatively high saturation with Na noted here was probably due to the combined influence of the soluble Na salts and the alkalinity.

As has been pointed out above, the complete saturation of a soil with a given base is conditioned upon the removal of the soluble products of the

reaction. When a neutral Na salt is used, only partial substitution of Na for the normally occurring Ca will result, unless the soil be subjected to prolonged leaching with a relatively concentrated solution of the salt. If, however, the solution contains soluble carbonate, in amounts sufficient to precipitate the displaced Ca and Mg as carbonates, the reaction may be taken to completion, or approximately so, by a single treatment and without leaching. In this case the end result will depend merely upon the concentration of Na in the solution and its alkalinity.

Once a soil becomes saturated with Na it will remain so as long as the concentration of Na salts is high and other soluble cations are excluded from the system. Although $CaCO_3$ is markedly soluble in neutral solutions of $NaCl$ or Na_2SO_4, its solubility is low in highly alkaline solutions of these salts. Be-

TABLE 2

Replaceable bases in extreme alkali soils

LABORA-TORY NUMBER	LOCATION	DEPTH	PROPORTIONS OF SOIL				RELATIVE PROPORTIONS			
			Ca	Mg	K	Na	Ca	Mg	K	Na
		inches	per cent	per cent	per cent	per cent				
4585	Fresno, Cal.	0–12	0	0	0.024	0.082	0	0	15	85
5190	Salt Lake, Utah	0–12	0	0	0.143	0.135	0	0	38	62
5696	Fallon, Nev.	0–6	0	0	0.031	0.563	0	0	3	97
6145	Tucson, Ariz.	0–6	0	0	0.072	0.174	0	0	19	81
6376	San Jacinto, Cal.	0–12	0	0	0.084	0.473	0	0	9	91
6377	San Jacinto, Cal.	12–24	0	0	0.052	0.842	0	0	3	97
6539	Davis, Cal.	0–12	0.079	0.054	0.091	0.495	12	14	7	67
6540	Davis, Cal.	12–24	0.053	0.078	0.072	0.472	8	21	6	65
6541	Davis, Cal.	24–36	0.069	0.113	0.056	0.364	11	31	5	53
6809	Los Alamitos, Cal.	0–6	0	0	0.060	0.118	0	0	23	77
7070	Logan, Utah	11–15	0	0	0.331	0.289	0	0	40	60
7073	Los Alamitos, Cal.	0–6	0.024	0	0.089	0.166	11	0	21	68
6139	Chino, Cal.	12–24	0.043	0.055	0.173	0.257	9	21	20	50
6140	Chino, Cal.	24–36	0.050	0.039	0.135	0.215	14	17	18	51

cause of this fact the presence of Na_2CO_3 operates to prevent the reversal of the exchange reaction, which would otherwise take place through the action of $CaCO_3$. In the presence of a high OH-ion and Na-salt concentration the solution processes are unable to dissolve $CaCO_3$ in amounts sufficient to displace the Na. This is the condition which obtains in many black-alkali soils.

It should also be pointed out in this connection that the concentration of the soil solution, which is in contact with the soil particles, is usually much greater than the concentration of an aqueous extract of an alkali soil. The soil solution of many alkali soils is, in fact, actually saturated with Na salts; otherwise the salts would not crystallize out. Although occasional rains may dilute the soil solution, its concentration again becomes high upon evaporation. Therefore, once a soil contains a high concentration of Na salts, in-

cluding Na_2CO_3, the exchangeable constituents become and tend to remain mainly Na compounds.

As has been stated, the soils reported in table 3 are less completely saturated with monovalent bases than those of table 2. With two exceptions the former do not contain Na_2CO_3 and in these cases the total concentration of Na salts is not high. These alkali soils still contain considerable replaceable Ca, but its substitution by Na has gone far enough to affect

TABLE 3

Replaceable bases in intermediate alkali soils

LABORATORY NUMBER	LOCATION	DEPTH	PROPORTIONS OF SOIL				RELATIVE PROPORTIONS			
			Ca	Mg	K	Na	Ca	Mg	K	Na
		inches	*per cent*	*per cent*	*per cent*	*per cent*				
6138	Chino, Cal.	0–12	0.186	0.080	0.142	0.148	36	25	14	25
6155	Arlington, Cal.	0–12	0.158	0.069	0.057	0.094	41	30	7	22
6297	Caldwell, Idaho	0–12	0.178	0.062	0.060	0.153	40	23	7	30
6298	Caldwell, Idaho	0–12	0.261	0.098	0.071	0.150	44	28	6	22
7074	Los Alamitos, Cal.	0–6	0.172	0	0.103	0.124	52	0	16	32

TABLE 4

Replaceable bases in alkali soils containing soluble calcium salts

LABORATORY NUMBER	LOCATION	DEPTH	PROPORTIONS OF SOIL				RELATIVE PROPORTIONS			
			Ca	Mg	K	Na	Ca	Mg	K	Na
		inches	*per cent*	*per cent*	*per cent*	*per cent*				
887	Fresno, Cal.	0–12	0.151	0.051	0.047	0.030	53	30	8	9
6157	Sutter Basin, Cal.	0–12	0.380	0.162	0.040	0.047	53	38	3	6
6158	Mendota, Cal.	36–72	0.333	0.074	0.014	0.019	70	26	1	3
6288	Imperial, Cal.	0–12	0.332	0.112	0.053	0.044	57	32	5	6
6372	Imperial, Cal.	0–12	0.433	0.089	0.029	0.025	70	24	2	4
6373	Imperial, Cal.	12–24	0.511	0.062	0.025	0.011	80	16	2	2
6374	Holtville, Cal.	0–12	0.554	0.093	0.019	0.015	76	21	1	2
6375	Holtville, Cal.	12–24	0.460	0.113	0.032	0.005	69	28	2	1
6522	Santa Ana, Cal.	0–12	0.594	0.109	0.034	0.022	73	22	2	3

their properties adversely. Their permeability is low; upon drying, hard crusts are formed and a good seedbed is difficult to prepare. When the concentration of electrolyte is lowered, these soils present highly dispersed systems. Such soils will not become normal merely by the removal of the soluble salts. The replaceable Na must also be dealt with in their reclamation, but the problem is less difficult than is the case with soils which are still more completely saturated with Na.

On the other hand, alkali soils such as are illustrated in table 4 do not become highly deflocculated when the concentration of soluble salts is reduced. Several of these soils contain extremely high concentrations of Na salts,

but the concentration of soluble Ca and Mg salts has effectively prevented the replacing action of Na. Such soils will become essentially normal when the excess of soluble salts is leached out. They may be readily reclaimed merely by drainage and flooding.

The results obtained with the three samples of soil from Los Alamitos, California, which were taken from the same field, are especially interesting. They afford a striking confirmation of the importance of replaceable Na in alkali soils. Two of these samples (6809 and 7073, table 2) contain 77 and 68 per cent, respectively, of their replaceable base as Na and very little replaceable Ca. Both were drawn from places where crops have failed. Water penetrates these soils very slowly indeed; they break up into hard lumps upon drying and a suitable seedbed is difficult to prepare. The other sample (7074, table 3), on the other hand, produces fair crops of cereals. It was found to contain 52 per cent of its replaceable base as Ca and only 32 per cent as Na. Its physical condition is considerably better than that of the other samples from this field.

In addition to these samples from Los Alamitos, California, we have also studied several others which were drawn from adjacent portions of the same general locality. These latter proved to be entirely different from those discussed above. Although they contained a high total concentration of soluble salts, Ca salts were present in considerable amount, and consequently Ca constituted their chief replaceable base. Upon leaching out the excess of soluble salts these soils exhibited the physical properties characteristic of non-alkali soils.

A similar though less pronounced condition was found in the Fresno region. The two samples reported (4585, table 2, and 887, table 4) were drawn from different portions of the same ranch. The latter contains much the greater total concentration of soluble salts, but because of the presence of considerable soluble Ca salts, it does not contain excessive amounts of replaceable Na. When leached with water its suitability for crop growth is restored. The former, on the other hand, is largely saturated with Na, and extensive field experiments have shown that its practical reclamation requires the application of a Ca salt, or some material which will make effective the small amount of $CaCO_3$ present.

Thus it is shown that a high proportion of replaceable Na goes hand in hand with low crop-producing power and poor physical conditions.

In many localities in western America there are areas of various sizes on which crops either fail entirely or else make unprofitable growth but which do not contain especially high concentrations of soluble salts. The physical condition of these soils is usually poor. Rains and artificially applied water never penetrate to a depth of more than a few inches and much of the water stands on the surface until evaporated. The soil is very sticky when wet and harsh when dry. When plowed it breaks into large lumps. Such places are locally designated as "slick spots."

The sample from Fallon, Nevada (5696, table 2) represents an extreme example of this condition, being taken from an area where no vegetation of any kind has been able to gain a foothold. The samples from Chino, California (6138) and Caldwell, Idaho (6297 and 6298, table 3) represent intermediate types of this condition. Here a weak growth of crops is obtained, but the yields are unprofitable. The tables show that the Nevada soil is practically saturated with Na and also contains a relatively high content of replaceable Na. The soils from Chino and Idaho, on the other hand, are only about one-fourth saturated with Na and contain considerable replaceable Ca. The poor physical condition of these soils is due largely to replaceable Na, and their treatment should be directed towards the substitution of Ca for the Na present. Although the concentration of soluble salts is not very high, they are none the less alkali soils. They represent areas where relatively high concentrations of Na salts accumulated at some previous period but which have been largely leached out by natural precipitation, thus leaving a relatively low concentration of soluble salts and an excess of replaceable Na.

SOLUBLE SILICATES

It was suggested above that certain alkali soils may contain appreciable amounts of silicates that are soluble in NH_4Cl solution. Reference is made to components other than those involved in the usual base exchange. These latter we prefer to regard as alumino-silicates,[4] that is salts of one or more of the various hypothetical alumino-silicic acids. In addition to the latter compounds it is probable that relatively simple silicates of Ca and Mg are also present in certain black-alkali soils. As is well known, Na_2CO_3 is a solvent for colloidal SiO_2, and soluble SiO_2 appears to be present to some extent in all alkali soils. When $CaCO_3$ is present the equilibrium must be extremely complex; it is possible that small amounts of $CaSiO_3$ may be formed. This substance is quite soluble in NH_4Cl and other salt solutions.

Such silicates, if present, may play an important rôle in black-alkali soils. When the alkalinity is reduced, the silicates would probably pass into solution to some extent and thus serve to displace Na. The Salt Lake (5190) and San Jacinto (6376 and 6377) soils seem to contain significant amounts of readily decomposable silicates of both Ca and Mg as well as carbonates of these bases.

Despite the fact that the Salt Lake soil is approximately saturated with monovalent bases, experiment has shown that it may be reclaimed by mere drainage and flooding. One of the Fresno soils (4585), on the other hand, contains very little $CaCO_3$ and apparently negligible amounts of soluble Ca silicate. Extensive field investigation has demonstrated that this soil is difficult to reclaim. Its practical reclamation, as pointed out above, requires

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[4] Exchange organic compounds are also present to some extent in the soils studied. In certain soils organic compounds probably constitute a considerable part of the exchange complex.

the artificial application of some substance that is capable of effecting the displacement of the replaceable Na.[5]

THE RÔLE OF $CaCO_3$ IN ALKALI SOILS

When an alkali soil which contains $CaCO_3$ is subjected to the leaching action of rains or irrigation, the concentration of soluble Na salts may finally be reduced, as suggested above, to a point where $CaCO_3$ will begin to be effective. Then the exchangeable Na will be gradually displaced by Ca with the simultaneous formation of Na_2CO_3. Several of the soils reported in table 2 behave in this way. Their content of soluble carbonate may be increased several fold by leaching with distilled water. As shown in a previous paper (1) $CaCO_3$ is not absolutely essential to the generation of Na_2CO_3 in Na-saturated soil, but the presence of the former certainly promotes the formation of the latter.

Moreover, it is possible, although not practicable, to reclaim the Fresno soil (4585) by prolonged leaching with distilled water. In this case the small amount of $CaCO_3$ present becomes effective. For example, Mr. P. L. Hibbard subjected a sample of this soil to continuous leaching with distilled water for several weeks. At the close of the experiment the soil was found to contain the normal proportion of replaceable Ca and a low amount of replaceable Na.

The importance of the displacing action of $CaCO_3$ was further demonstrated by subjecting samples of four of the soils reported in table 2 to ordinary dialysis for a period of 3 weeks. The Na thus displaced diffused through the membrane as Na_2CO_3 and by frequent change of the exterior solution the displacing action of $CaCO_3$ was made continuous. The results are shown in table 5. At the close of the experiment it was found that these soils had sustained the loss of a considerable part of their $CaCO_3$. The chief base which passed out of the soil was Na. The dialysis served to bring about a striking change in the physical properties of these soils: whereas they were extremely deflocculated and impervious to water at the outset, this was not true after dialysis. Hissink (15) reports that since the land has been drained, $CaCO_3$ has gradually brought about similar effects in certain salt-marsh soils of Holland.

It is in this connection that decaying organic matter is especially important in black-alkali soils. The decomposition set up by microörganisms brings about the formation of CO_2 and other organic solvents of $CaCO_3$ which in turn displace the Na; the latter may then be leached out as the bicarbonate.

As suggested by Kelley and Thomas (17) and more recently confirmed by

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[5] The irrigation water that has been used in connection with the experiments on the Salt Lake soil contains considerable Ca and Mg, which may have influenced the results favorably. In fact we believe that the composition of the irrigation water is very important in the reclamation of alkali soils.

Samuels,[6] the H ions of dilute acids, such as carbonic acid, and the oxidation products of sulfur, may also serve to displace the Na of alkali soils. The exchangeable Na compounds that occur in alkali soils are highly reactive. When treated with an acid, or when sulfur undergoes oxidation in contact therewith, these compounds are readily reacted upon, with the resulting formation of soluble Na salts and acid silicates. If Na_2CO_3 is present, the acid acts upon both the carbonate and the exchangeable Na compounds simultaneously. Moreover, it appears to be impossible to neutralize the Na_2CO_3 of black-alkali soils, or to convert it completely into an insoluble carbonate by the application of gypsum, without affecting the exchangeable Na compounds. The practical treatment of black-alkali soils must, therefore, necessarily involve the exchangeable compounds as well as the soluble carbonate.

The results of laboratory and field experiments agree in showing that elemental sulfur has great promise in the reclamation of black-alkali soils. Because of its great activity, the H ion formed by the oxidation of sulfur is able to displace Na from the exchange compounds, with the resulting formation of compounds that are unsaturated with bases. In consequence, the physical

TABLE 5

Replaceable bases after dialysis

LABORA-TORY NUMBER	LOCATION	PROPORTIONS OF SOIL				RELATIVE PROPORTIONS			
		Ca	Mg	K	Na	Ca	Mg	K	Na
		per cent	*per cent*	*per cent*	*per cent*				
4585	Fresno, Cal.	0.093	0	0.010	0.013	85	0	5	10
5190	Salt Lake, Utah	0.089	0	0.056	0.043	56	0	19	25
5696	Fallon, Nev.	0.400	0.037	0.043	0.086	72	11	4	13
6376	San Jacinto	0.307	0	0.095	0.182	60	0	9	31

and chemical properties of the soil may be materially improved, but, as stated in a previous paper from this laboratory (1), the fundamental injury wrought in the soil by Na salts will not be overcome merely by substituting H for Na in the replacement complex. It is necessary to restore Ca to its normal position in the molecule. Fortunately this may also be effected through the intervention of $CaCO_3$, which is commonly an important constitutuent of black-alkali soils. When the OH-ion concentration has been sufficiently lowered this compound comes into action, thus permitting its Ca to pass gradually into the exchange complex and displace the Na.

The soils from Chino, California (6138, table 3, and 6139, table 2) are interesting in this connection. They were taken at different depths below the surface from a single small area not more than 20 feet in diameter on which crops have failed. The surrounding land is quite productive. The entire

[6] Unpublished paper read before a meeting of the Western Society of Soil Management and Plant Nutrition, Stanford University, June 24, 1924.

field has been devoted to alfalfa culture for several years.   More or less farm manure has been applied to this spot and copious irrigation has been practiced.   It will be noted that the surface soil (6138) contains considerably more replaceable Ca and less replaceable Na than the subsoil (6139).   It is probable that the surface soil was quite similar to the subsoil before the land was brought under cultivation, but the high content of $CaCO_3$ present has been made effective through the use of manure and heavy irrigation.

Moreover, since the rate of diffusion is probably insufficient to maintain perfect homogeneity throughout the soil solution, the continuous formation of acids by sulfur oxidation, organic decomposition, and CO_2 excreted by growing plants may enable $CaCO_3$ to influence the plant apart from its effect on the soil.   At the several points of contact between the absorbing roots and the particles of $CaCO_3$ it seems probable that the plant may be able to absorb Ca despite the fact that the soil mass contains excessive amounts of exchangeable Na.   As will be discussed more fully elsewhere, the toxicity of Na-saturated soil seems to be due in considerable part to its deficiency in available Ca.

Thus it is shown that $CaCO_3$ performs an important function in alkali soils.   Its presence in the first place may lead to the formation of Na_2CO_3, and in the second place it may serve to bring about the restoration of favorable chemical and physical properties.   The long known antidotal effect of $CaCO_3$ in alkali soils is thus explained on the basis of simple chemical principles.

THE PHYSICAL PROPERTIES OF ALKALI SOILS

As is pointed out above, upon flooding the land the permeability of alkali soils may undergo pronounced reduction.   The decrease in permeability may begin to manifest itself long before the soluble salts have been completely leached out, and when the concentration of soluble salts becomes relatively low the further penetration of water may cease altogether.   This effect is sometimes produced in alkali soils that contain only a low content of clay, but is most marked with heavy soil types.   Alkali soils which contain considerable amounts of soluble Ca and Mg salts, however, are not thus affected by leaching.

If a normal soil is treated with different salts and then leached with water, its physical properties are variously affected, depending upon the salt used. Even should the leaching be continued until the last trace of the added salt has been removed, the treatment with a Ca salt will produce a relatively porous soil.   On the other hand, Na salts produce extreme impermeability. These effects are undoubtedly traceable to the exchange of bases.

The complex involved in base exchange[7] is relatively stable chemically when

[7] Various writers refer to this complex as being of an adsorption character. We prefer to look upon it as being essentially chemical, but, as Drummond and Page (5) pointed out recently, the two views are not greatly different. In both views the bases are considered to be chemically combined with the alumino-silicate or organic part of the complex.

Ca is the chief exchangeable base. Its solubility, hydrolysis, and ionization are probably low. The Na complex, on the other hand, is much less stable and more soluble, and tends to undergo pronounced hydrolysis, as shown by its alkalinity. The reactivity of the Na compounds is shown by the fact that dilute acids will combine with them in preference to carbonates; they undergo continued hydrolysis and ionization as indicated by the rate at which Na may be split off under conditions of dialysis. If conditions of electro-dialysis are employed, the replaceable Na may be separated from the soil very rapidly indeed. Sodium is more easily displaced than any other cation with the possible exception of Li. The Ca compounds are not so readily decomposed; they do not hydrolyze to any considerable extent; and their rate of dialysis is only a small percentage of that of the Na compounds.

These facts probably have a direct bearing on the physical properties of alkali soils. It has been suggested (1, 12) that alkalinity is primarily responsible for the impermeability of soils that are high in exchangeable Na. That OH ions have a stabilizing effect on suspensions of electro-negative colloids is, of course, well known, and the fact that the Na complex is hydrolyzable, with the resulting effect of increasing the OH-ion concentration, probably influences the physical state of the soil. We have noted, however, that unless the H-ion concentration of the solution was brought to approximately pH 3 the rate of settling of a suspension of Na-saturated soil was not materially increased by the addition of HCl.

As was pointed out by Dayhuff and Hoagland (2), there is considerable evidence that the coagulating effect of acids is due as much to the bases brought into solution by the action of the acid on the soil constituents, as it is to the H ions. The most effective coagulating cation that is brought into solution by the interaction of dilute acids and normal soils is Ca. The soil used in our experiment did not contain $CaCO_3$ and, since its replaceable Ca had been previously substituted by Na, the reaction with the dilute acid consisted mainly in the substitution of H for Na. The latter, however, has a relatively low coagulating power. In fact it requires a rather high concentration of Na salt to effect the coagulation of Na-saturated soil.

The results of these and other experiments strongly indicate that the OH ion is not the chief dispersing agent in Na-saturated soil. The decomposition and ionization products of the Na complex are probably hydrated. The fact that the relative degree of dispersion of a soil when saturated with different bases stands in the order Ca<Mg<K<Na<Li, which is the exact order of the hydration of their respective ions, at once suggests, as was recently discussed by Wiegner (24), that the hydration of ions is closely connected with the physical properties of soils.

It should be emphasized that the reactivity of replaceable Na compounds and the ease with which the Na may be displaced by other cations, render it impossible to effect the coagulation of alkali soils by the addition of electrolytes without at the same time bringing about a substitution of cations.

In this regard H ions are particularly potent. Any material increase in the H-ion concentration above that of pure water brings about the substitution at once. Hydrolyzable salts which yield acid solutions, such as Fe and Al salts, also bring about the substitution, but in this case the substitution is probably effected chiefly by H ions instead of Fe and Al. At any rate the coagulating action of dilute acids, or Fe and Al salts, inevitably involves chemical reactions with the exchange compounds.

Despite the great importance of the exchange reaction in alkali soils it should not be inferred that adverse physical and chemical properties are always due to base exchange. In fact, a concentration of Na_2CO_3 too low to produce substantial base exchange may serve to produce deflocculation and generally adverse physical effects. For example, we have examined an impervious soil from New Mexico whose deflocculation seems to be due to small amounts of Na_2CO_3 and not to exchangeable Na compounds.

SUMMARY

1. The investigations reported in this paper emphasize the importance of the chemical reactions which take place between alkali salts and soils. These reactions consist mainly in an exchange of bases, in consequence of which important chemical and physical properties are produced. As Na is substituted for the normally occurring Ca in the exchange complex, the soil becomes less and less permeable to air and water. If the substitution goes very far, injurious alkalinity will be produced upon leaching out the excess of salts. Such soils may then be seriously toxic to plants.

2. The alkali soils studied, conveniently fall into three classes:

(a) Soils whose replaceable Ca and Mg have been mainly substituted by Na. This class is characterized by a high content of water-soluble Na salts, a low content of soluble Ca and Mg and usually more or less Na_2CO_3. Such soils become extremely impermeable upon leaching out the soluble salts. (b) Soils in which the substitution of Na has taken place to a limited extent only. These soils may also contain a high concentration of Na salts, but, if so, they also contain considerable soluble Ca. Such soils are less impervious than those of the first group. (c) Soils which do not contain abnormal amounts of replaceable Na. This class is characterized by a relatively high concentration of Ca and Mg salts. In this case the concentration of Na salts may be extremely high without producing any considerable substitution of bases. Soils of this kind do not become impermeable upon leaching out the salts.

Generally speaking the practical reclamation of soils of the first group will require the application of special treatment. Those of the second group may also be benefited by special applications, but the amount of material required will certainly be less than is needed by soils of a similar type which contain still more replaceable Na. On the other hand, alkali soils which contain considerable amounts of soluble Ca salts may be reclaimed by flooding and drainage without any other treatment.

3. In the practical treatment of alkali soils the water-soluble salts must,

of course, be considered, and leaching with water is the only practical method of reducing the concentration of soluble salts. If an excess of Na_2CO_3 is present, it too must be dealt with, but the ultimate objective in alkali reclamation should be the restoration of the normal proportions of replaceable Ca as well as the removal of the water-soluble salts. It is in this connection that gypsum is important.

4. The neutralization of Na_2CO_3 by acids and its conversion into an insoluble carbonate by the application of gypsum, proceed hand in hand with transformations in the base-exchange complex. The amount of material to be applied, therefore, must exceed that required by the carbonate alone. If the soil contains a large absolute amount of exchangeable Na, a correspondingly large quantity of treating material will be required. In some cases this may be economically impossible.

5. Calcium carbonate is commonly present in alkali soils and may play an important rôle in their reclamation. Elemental sulfur is especially promising with such soils. Certain alkali soils also apparently contain easily decomposable Ca silicates which may become effective during the course of the treatment.

6. In the examination of alkali soils it is important to consider:

(a) The concentration and composition of the soluble salts present, (b) the replaceable bases, (c) the content of easily decomposable Ca compounds, such as $CaCO_3$ and possibly certain relatively simple Ca silicates, (d) the composition of the irrigation water, and (e) the drainage conditions.

The importance of the last-named factor can scarcely be over-emphasized, for unless the salts can be leached out, and unless the water table is kept low enough to prevent the capillary rise of soluble salts, the benefits accruing from any treatment will be only temporary.

7. In this investigation a detailed survey of the several localities referred to was not undertaken. The soils reported were drawn, however, from many localities and widely separated places. They are believed to be representative of the important alkali areas of America. The conclusions drawn, therefore, are probably widely applicable, and for the most part are in close agreement with the conclusions of Gedroiz, Hissink, and other contemporaneous students of this subject.

It now seems certain that the accepted teachings of earlier students of alkali soils must be considerably revised. The ideas, widely current among alkali reclamation engineers and agronomists in America and elsewhere, that an alkali soil is merely a soil which contains an excess of soluble salts, that the removal of this excess will restore normal properties to the soil, and that mere drainage with or without flooding will suffice to reclaim the land, are only partial truths. These ideas neglect the important fact that soluble Na salts bring about deep-seated chemical changes in certain components of the soil, which in turn lead to important physical effects, and which are not overcome

by drainage.   The toxicity of alkali soil may be due not merely to the concentration of soluble salts.   The relatively insoluble yet readily exchangeable components may play an equally important part.

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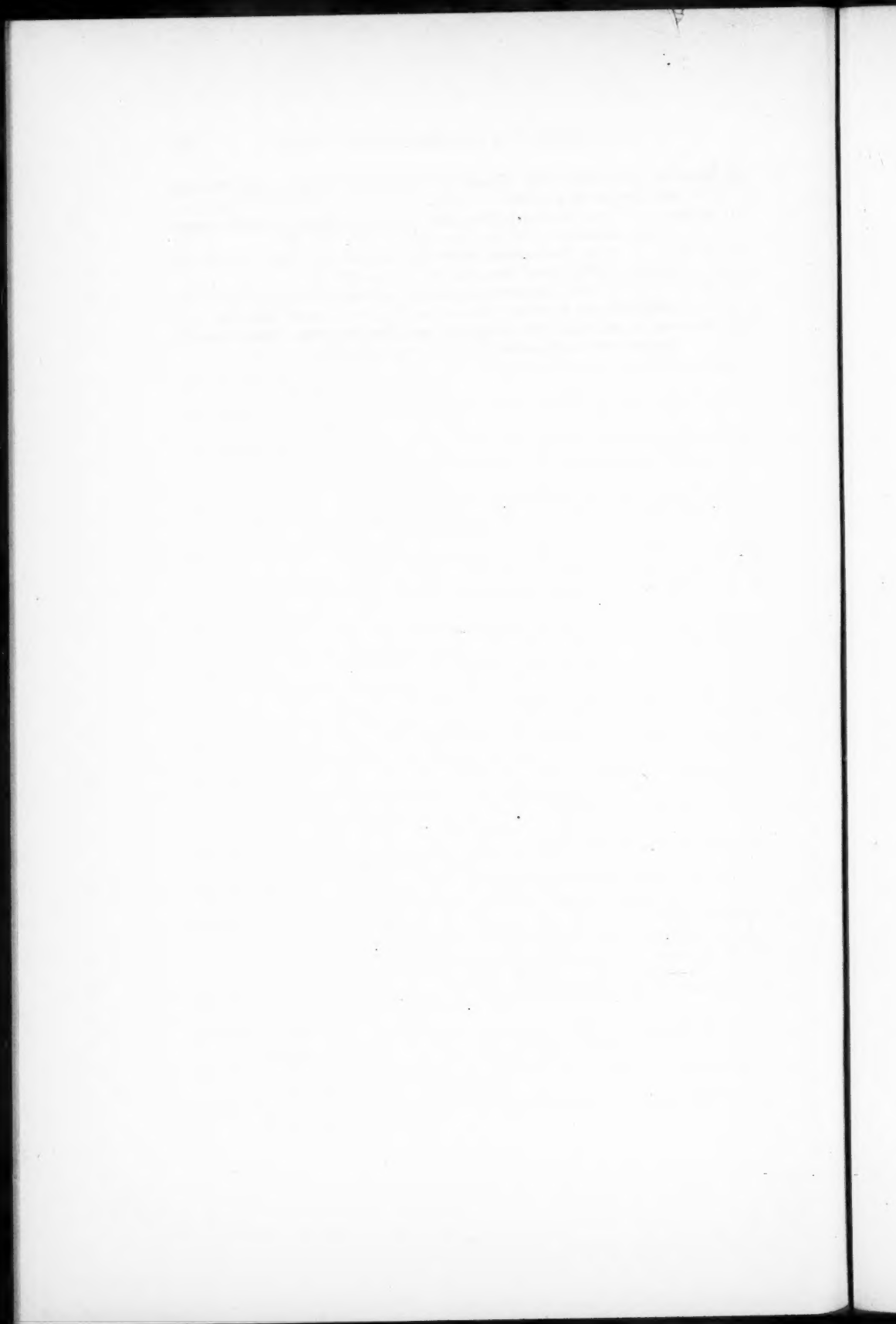
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		Corn	Oats	Wheat
			Bushels per acre	
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Plot 17	Nitrate of Soda	35.78	38.03	13.84*
Unlimed Section—First 10-year period (1894-1903)				
Plot 24	Sulphate of Ammonia	44.87	46.15	20.41
Plot 17	Nitrate of Soda	42.66	43.61	18.52*
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Plot 17	Nitrate of Soda	45.04	50.85	22.19*
Limed Section—20-year average (1904-1923)				
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